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LECTURE NOTES

on

Forest Engineering

for

Ranger Students in Northern India

By

D. DAVIS, B.A., I.F.S.,
Instructor, Forest College, Dehra Dun.

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PREFACE.

The need for a new and up-to-date manual of forest engineering for use in the Rangers' Forest College at Dehra Dun has long been felt. The Manual of Forest Engineering for India by C. G. Rogers, I.F.S., was published in 1900, and is not now suitable for use. It is in many respects out of date, and does not contain much that is now necessary. It is also too long, and full of unnecessary details and repetitions. In 1929 " Engineering for Forest Rangers in Tropical Countries " was published by A. H. Lloyd, I.F.S. This manual has special reference to Burma, and though it is excellent in many respects, it does not deal with many things, *e.g.*, masonry buildings, which are taught at Dehra Dun.

Thus, when the writer came to the Forest College as Instructor in 1930, he found it necessary to spend much time in compiling lecture notes for dictation to the students, who had no suitable manual to read, and to which they could refer. The dictation of these notes in lectures meant that there was often barely time for the necessary explanations and elaborations. It has, therefore, been considered advisable to print the notes, so that in future each student can have a copy of them from the beginning of the course. It is hoped that they will in future prove of some use in the College by saving lecturers much time and trouble in the preparation and delivery of lectures, and students much labour in taking down notes.

Owing to lack of time it has been impossible to include any diagrams, which are, of course, in many cases essential to the proper understanding of the text, and it is intended that the necessary diagrams should be given to students on the blackboard during lectures.

Again owing to lack of time it has been necessary to leave out several items, such as transport of timber, which would normally be dealt with in a manual of forest engineering. It is hoped, therefore, that this volume will not be looked upon as a very inadequate attempt by an amateur to write a manual, but will be accepted as nothing more than its title implies, an attempt to collect in the form of lecture notes most of the essential information which a forest ranger in northern India should have at his disposal when studying forest engineering.

These notes, as all such notes are bound to be, are mostly collected from other books on engineering, supplemented here and there from the writer's own very limited practical experience. The following books have been freely used :—

Engineering for Forest Rangers in Tropical Countries, by A. H. Lloyd.

Roorkee Treatise on Civil Engineering—Sections I to VIII.

Military Engineer Services Handbook—Vols. I to III.

Manual of Forest Engineering for India, by C. G. Rogers—Vols. I to III.

Grateful acknowledgment is hereby made.

D. DAVIS.

DEHRA DUN, INDIA;
1st April, 1933.

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LECTURE NOTES

on

Forest Engineering.

I. INTRODUCTION.

A Forest Ranger is responsible for the construction and maintenance of roads, bridges, buildings, and wells, and to a greater or lesser extent for the extraction and transport of timber, and for various other minor engineering works. Roads and bridges are essential both for communication and to enable timber and other forest produce to be removed from the forests. Buildings are necessary to house the large staff which is employed to work the forests; and where good water cannot be obtained from springs or streams, it is necessary to sink wells. A Ranger may have very little to do directly with the extraction and transport of timber, as this may be managed by the contractors who buy it. But in many places, especially where departmental extraction is practised in the hills, it may be necessary to make timber slides, wire ropeways, and similar means of extracting timber. In any case a knowledge of the engineering methods to be employed is necessary, whether the Ranger is directly responsible for them or not.

It will thus be seen that the engineering knowledge required of a Ranger is very wide and varied. It may be possible for him to carry on in some sort of way without a great deal of knowledge and skill, where local workmen and contractors are available to give help. But the work done will be bad and expensive. A Ranger who is a good and keen engineer gains tremendously in general efficiency and in the power to satisfy and please his superior officers.

II. MATERIALS USED IN FOREST ENGINEERING.

1. Introduction.

1. Before undertaking any work a knowledge of the materials to be used is essential. A very important part of all constructional work is to make sure that suitable materials of good quality are being used, and this cannot be done without a detailed knowledge of them. In forest buildings and other works materials available near at hand have generally to be used in preference to materials imported from a distance, even if the latter are better, owing to the high cost of transport to the site; *e.g.*, most bridges are of timber, though if made of masonry or steel they would be more durable; and buildings in Burma and Assam and other similar provinces are made entirely of timber and bamboos, chiefly because skilled masons and builders are difficult to obtain. It is important to remember to make use of local experience in the choice of materials, and to study local conditions carefully before trying to introduce new methods or materials. Climatic and other conditions in different parts of India vary greatly, and available materials also vary greatly; *e.g.*, no stone is available over large tracts in the plains, and only in certain places is suitable earth for brick-making found. Thus the types of buildings, bridges, etc., may vary greatly.

The chief materials used for building and other engineering works will be dealt with in detail.

2. Stone.

2. A. *Chief Uses.*—Buildings, revetment and other walls, bridge abutments, and road metalling.

3. B. *The choice of the kind of stone* is usually limited to that available in the locality owing to the high cost of transport. If more than one kind is available, the choice depends on the quality.

4. *Qualities necessary.*—(1) Durability. (2) Facility of working. Any stone which is sufficiently durable will be strong enough for forest work. But stones which are very difficult to work may be impossible or too expensive to use in the forest. Durability means the power of resisting weathering, *i.e.*, the decomposing

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action of the atmosphere. Non-durable stone wears away and disintegrates more or less rapidly.

5. C. *Tests of durability*—

(*a*) A freshly broken surface must be bright, clean, and sharp, without loose grains, and without seams or veins containing material not well cemented. It must not be dull and earthy.

(*b*) The hardest and heaviest stone with the finest grain is usually the most durable. Porous and coarse-grained stone is not durable.

(*c*) Porosity test (especially for sandstones)—

> Weigh when dry and again after soaking in water for 24 hours. The more durable stone is that which absorbs least water. It must not absorb more than $\frac{1}{30}$th its weight of water.

(*d*) Earthy stones are not durable. If soaked in water for half an hour and the water becomes discoloured, it means that the stone contains earthy matter, and mineral matter easily soluble in water, and is not durable.

(*e*) Look at old buildings built of the stone which it is proposed to use, and see how the stone has weathered. The surface should be hard, and all corners sharp and true.

Also look at exposed places on the quarry face for the amount of weathering.

6. D. *General Rules to remember when using Stone*—

(*a*) Do not use stone from the surface, which has been long exposed and weathered.

(*b*) Freshly quarried stone (especially limestones and sandstones) has "quarry sap" in it. Protect it from frost until this has evaporated. It is more easily worked before this has evaporated.

(*c*) Granites and other hard stones are more durable if left with a rough finish. Softer and more absorbent stones are more durable if left with a smooth surface, which can often be obtained by rubbing.

(*d*) When using stratified stone, lay it with the strata parallel to the ground, except in arches where the strata must be parallel to the radii of the arch; *i.e.*, those at the top will be at right angles to the ground.

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7. E. *Classification of the Commoner Stones.*—Three main groups:—

(1) *Igneous*, which come from the earth's original crust, and were formed by the action of fire. They are not stratified and contain no fossils.

(a) *Granite.*—Crystalline, very hard, rough surfaced. Very strong and durable. Difficult to work.

Used for buildings, where it is possible to work it. Good for road metal.

(b) *Blue or black basalt or Trap.*—Originally formed as lava by volcanic eruption. Compact and heavy. Weathers well, but varies in quality. Very hard to work.

Used for road metal, but seldom for buildings owing to difficulty of working and to its dark colour.

(2) *Metamorphic.*—Probably originally sedimentary and stratified, but subsequent action of heat changed their appearance and made them more or less crystalline. Stratification absent or not very obvious. Contain no fossils.

(a) *Gneiss.*—Something like granite, but more or less stratified. Much the same qualities as granite.

Used for road metal, but not often for buildings.

(b) *Slates.*—Originally sedimentary clay, but subjected to great heat and pressure. Splits easily along "cleavage planes", which are at right angles to the original strata. Colour usually grey, dark blue, or practically black. Close-grained, compact, and does not absorb water. A good slate has a clear dark colour, uniform texture, and a ringing sound when struck.

Used for roof tiles, floor slabs, cisterns, and other things for which large flat slabs are required. Not used for roads.

(c) *Marble.*—A metamorphosed limestone—pure carbonate of lime. Crystalline and usually white, but sometimes yellow, red, or black, or a mixture of colours. Very durable and hard, compact, translucent, and takes a fine polish. Easy to work.

Rare and therefore expensive and generally only used for ornamental work.

(d) *Quartzite and Mica Schist* are two common rocks, which are of no use for building, but can be used for road metal.

Quartzite is a hard, compact, stratified rock, white or brownish in colour, and breaking with a lustrous fracture. It is a metamorphosed sandstone composed of quartz grains cemented with silica. Mica schist is crystalline and fine-grained and divides easily into thin sheets. It is composed of mica and quartz, and is grey, greenish, yellowish, or brownish black in colour.

(3) *Stratified or true Sedimentary.*—Preserved in the condition in which they were originally deposited under water. Generally more or less obviously stratified and often contain fossils.

(a) *Limestones.*—Chiefly carbonate of lime mixed with lesser quantities of other minerals and impurities. Vary greatly in colour and quality. May be white, yellow, grey, dark blue, or mottled. The best qualities are generally grey or bluish. Fairly durable if of good quality, and easy to work.

Tests for limestone:—Effervesces in contact with acid. Knife scratches leave a well-defined line filled with white powder. The better qualities are used largely for buildings and road metal. It is frequently burnt for lime.

Kankar is a special form of limestone found in nodules and layers in the plains of north India. Chiefly used for lime burning, and when no other stone is available, for road metal, for which it gives a smooth surface, but wears out quickly.

(b) *Sandstones.*—Composed of grains of sand (quartz) cemented with various substances such as lime, magnesia, etc. Varies greatly in colour and quality—generally yellowish, red, brown, grey or bluish white. Durability depends chiefly on the cementing material, those with least lime and iron being the best. Those with a fine grain are generally better than those with a coarse grain, and sharp grains and a small quantity of cementing material are good signs. Easily worked.

Test:—will scratch steel.

Good qualities much used for buildings. Generally too soft for roads, but the harder varieties are often used.

8. F. *Collection of Stone and Blasting.*—Generally by quarrying (*i.e.*, by excavating from a place where stone is found naturally). Also by collecting boulders from a stream bed, but only if quarrying is impossible.

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A quarry is generally on a hillside, and should if possible be above the site of the work, as it is easier to take stone out downhill. The road from the quarry should have an easy gradient.

If the stone is divided by natural joints and cracks, drive in wooden wedges, which can be expanded by wetting, and then the blocks of stone can be levered out with crowbars. A combination of drilling and wedging is sometimes used, if there are no natural fissures. A primitive method is to light a fire on the surface and then pour cold water on the hot rock. This splits the rock.

If the above methods are not successful, blasting with explosives must be employed. Blasting may be required not only for obtaining stone for buildings and other constructional works, but also for removing rock in road making in hilly country or in floating streams. The procedure is much the same in all cases, but gunpowder (blasting powder) is generally used when large blocks of stone are required for building work, etc., and dynamite, which is much more powerful, is generally used in road making and in other cases where all that is required is to remove masses of rock regardless of whether they are shattered into small pieces or not. Certain details of procedure vary according to which explosive is used.

For details of blasting see Lloyd's "Engineering for Forest Rangers", pages 210 to 216, and the "Roorkee Treatise on Civil Engineering", Section I, pages 12 to 16.

9. G. *Stone Dressing.*—The large rough blocks of stone obtained from the quarry, or the large boulders obtained from a river bed, have to be cut to the required size and shape. Except for very rough work this requires skilled labour and special tools, various axes, hammers, and chisels being used.

3. BRICKS.

10. A. *Uses.*—For buildings, well linings, retaining and other walls, bridges, and other miscellaneous works. Other things being equal brick is more expensive than stone masonry. Bricks must be used for buildings, etc., wherever suitable stone is not available, unless it is decided to dispense with both and to use nothing but other materials, *e.g.*, wooden buildings in Burma and Assam, and reinforced concrete buildings, which are being largely made now-a-days in the larger towns. Bricks are also often used in stone buildings in places where finer work is required; *e.g.*, round doors and windows and in arches, etc.

11. B. *Definitions.*—Bricks are made of tempered clay formed in a mould to the requisite size and shape and dried in the sun.

Sun-dried bricks are called "kachcha".

When hardened by being burnt they are called burnt bricks or "pakka". All bricks in a kiln cannot be burnt to the required extent.

When partially burnt they are yellowish and are called "pila".

When overburnt they are dark-coloured, and with excessive burning they fuse and melt and become distorted and often become vitrified (more or less glass-like). They are also often joined together in lumps. Badly overburnt bricks are called "jhama".

N.B.—Kachcha bricks are only used in temporary buildings, or in the superstructure of permanent buildings when pakka bricks would be too expensive.

The Frog of a brick is the hollow in the upper surface to provide a key for the mortar joint.

12. C. *Qualities of a good burnt brick*—

(1) Regular shape and uniform size.

(2) Sharp well-defined edges and corners.

(3) Free from cracks or lumps.

(4) So hard that the finger nail cannot make a scratch or dent.

(5) Should emit a clear ringing sound when struck together or tapped with a pencil or hammer.

(6) Clear and uniform colour (may be light red, but deep red or copper colour is best—colour depends on nature of brick earth and degree of burning).

(7) Should not absorb more than $\frac{1}{10}$th its dry weight when soaked in water for 6 hours.

N.B.—Underburnt bricks crumble when exposed to rain or laid in damp places.

13. D. *Classification of bricks*—

1st Class—as above.

2nd Class—fairly well burnt and ringing clearly when struck but somewhat uneven in shape, and may be partly vitrified.

3rd Class—pila or jhama.

14. E. *Weight and size and number required for a work.*—Weight of burnt bricks 120 lbs. per cubic foot.

Standard size $9 \times 4\frac{3}{8} \times 2\frac{3}{4}$ inches.

The breadth is just less than half the length, so that 2 headers with $\frac{1}{4}$ inch mortar joint between will occupy the same space from side to side as one stretcher.

1,400 bricks of standard size are required for 100 cubic feet of masonry allowing for mortar joints and breakages. When calculating the number to be burnt, allow for wastage in burning. Probably 50 to 60 per cent. of bricks burnt will be 1st class, and 20 to 30 per cent. 2nd class. To get 1,400 1st class burn 2,500 if a good outturn is expected, or 3,000 to be quite safe.

Never use bricks of different sizes in the same work.

15. F. *Brick Earth.*—Consists of clay mixed with sand and a few other mineral substances (lime, magnesia, iron, etc.). Good earth should be $\frac{3}{5}$th clay, $\frac{1}{5}$th sand, $\frac{1}{5}$th other minerals.

It is difficult to tell a good brick earth. It may be tested in the following ways:—

(*a*) If tempered to the right consistency and squeezed in the hand it should leave the fingers clean. If it sticks to the fingers it is too stiff or 'fat', *i.e.*, has too much clay in it.

(*b*) If a few bricks are moulded as an experiment and dried in the sun they should keep their shape and not crack.

(*c*) The best test is, if possible, to burn some bricks and see the result.

If the earth is too fat, bricks are liable to shrink too much and crack in drying, and are more likely to be burnt imperfectly.

If the earth is too loose and sandy, the bricks will be too soft, and when burnt will be brittle and more apt to fuse and become vitrified.

A little lime helps in binding the brick, but must be finely divided.

Too much lime causes bricks to melt and lose their shape in the kiln.

Lumps of lime become quicklime when burnt, and when the bricks become wet later on this causes disintegration.

Salts are bad, and if present in considerable quantity cause melting and loss of shape during burning.

Oxide of iron helps to bind the brick and gives it its red colour.

Too much iron makes it a very dark colour.

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16. G. *Preparation of Brick Earth.*—A sufficient water supply is the first essential.

Remove the surface soil. Dig the earth a week or more before required for moulding. Remove all vegetable matter, roots and weeds, etc., and stones, as they make the bricks crack, and also cause holes to appear during burning. Tempering is important. Break the earth thoroughly, water it, and knead it well under foot till it becomes free from lumps and a homogeneous mass. Then cover it with cloths or mats and leave it to dry gradually till it is of the right consistency. It must be stiff, *i.e.*, dry enough for the bricks to stand on edge when turned out. Moulders are liable to turn out bricks too soft, as it is easier. If there is too much water in the earth, the bricks will probably lose shape when set up to dry and will be brittle.

17. H. *Moulding.*—The moulds or frames are a little larger than the size of a burnt brick to allow for shrinkage in drying and burning. Shrinkage is greatest during drying and only a little during burning. Moulds are usually made with inside dimensions $\frac{1}{10}$th greater than those of the burnt brick (*i.e.*, $9\frac{9}{10} \times 4\frac{13}{16} \times 3\frac{1}{40}$ for standard size). But it is advisable to test, as shrinkage varies in different earths. Moulds may be of wood or iron. The ends project for handles. If made of wood use hard and tough wood (*e.g.*, *sissu-Dalbergia sissoo*) and it must be well-seasoned. Protect the edges with metal strips screwed on. The moulding and drying ground must be level, and be rubbed smooth, plastered, and sprinkled with sand. To prevent clay sticking to the mould use sand or water. Sand is better, as the brick will have sharper edges. A lump of clay is rolled into shape a bit bigger than the mould and is slapped into the mould filling all corners. Superfluous earth is cut off with a wire. Moulding can be done on the ground or on a board.

(1) If on the ground the mould is lifted and the brick left on the ground.

(2) If on a board (a slab of wood a bit bigger than the mould and with a projection for the frog):—

(*a*) Mould and board are together inverted on to the ground and then lifted up so as to leave the brick on the ground on its broad face.

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(*b*) A thin pallet board is placed on top, and the mould, brick, and pallet are lifted off the board, reversing them in the process; the mould is then tapped to loosen the brick and is lifted off the brick; a boy then places another pallet on top of the brick and lifts up the 2 pallets with the brick between, takes it away, and places it on edge in the drying ground.

Of these methods (1) is easier to do, but the bricks cannot be put very close together, and the under-surfaces of the bricks are rough and are apt to stick to the ground. (2) (*a*) is better than (1). The bricks have a better under-surface. It is the usual method in Dehra Dun. (2) (*b*) is the best, as bricks on edge dry better and more quickly, and take up less space.

A good moulder does 800 to 1,000 bricks a day.

18. J. *Drying.*—The drying ground should be raised to prevent flooding. If rain is expected, have light bamboo and grass frames to cover the top and ends of the stacks, and put heavy boards on top to prevent the frames from being blown away.

Bricks, if lying flat, must be put on edge after a short time. Always reverse them later on. Then pile them on edge in stacks leaving spaces between each brick for air circulation. The bricks in each layer must be laid across those in the layer below. Bricks must be left in the stacks till they are thoroughly dry and hard. If put in the kiln while damp, heat cracks and distorts them. Time of drying from 8 days in winter to 3 days in the hot weather. Bricks are not made in the monsoon.

19. K. *Brick Burning.*—Great skill is required in stacking the bricks for burning, and in regulating the burning properly.

There are 2 distinct methods of burning:—

20. (A) *Clamp or Pazawah.*—The floor is quadrilateral and slopes up at an angle of 15°. The lower end is below ground and is shorter than the upper end. Alternate layers of fuel and bricks are built up. The 1st layer is of fuel. Each layer of bricks is of 4 or 5 courses on edge (18 inches to 2 ft. high) with spaces between bricks. The layers of fuel are 2 ft. 6 in. thick. When one-third the total number of bricks to be burnt has been laid, the fuel is fired from the lower end, and burning goes on while loading proceeds, so that the draught will be sufficient at first for the fire to get well started. When loading is finished plaster over with mud. The fuel is grass, cowdung, and litter, as wood burns too quickly. A clamp takes a long time to burn and cool—one for 2 or 3 lakhs of bricks takes 6 months. It is useful when plenty of suitable fuel is available and time is no object. But burning cannot be regulated easily and is not uniform and many pila and jhama bricks are produced. Furthermore owing to the sinking of the upper layers as burning proceeds many bricks are distorted and cracked. It is not suitable for the forest, as wood fuel cannot be used.

(B) *Flame Kiln or Bhatta.*

There are 2 chief kinds.

21. (1) *Allahabad Kiln.*—A rectangular walled enclosure 18 ft. wide and 12 ft. high and of a length sufficient for the number of bricks to be burnt.

A kiln 18 × 12 × 50 ft. will contain about 110,000 bricks.

There are 2 wide doorways at each end for loading and unloading, and these are bricked up during burning. Flues at intervals of 4½ ft. centre to centre go across from side to side. They are about 4½ ft. high, the lower portion being in trenches 1 ft. deep and 1¼ ft. wide at the bottom. Bricks are stacked on edge between the flues with slight spaces between each brick, the 8th, 9th and 10th courses being corbelled out to meet over the flues. Above this bricks are stacked " three upon three ". The flues are open at the ends and fires are fed through the openings. Wood fuel is used, about 100 c.ft. for 1,000 bricks. Half way along each flue is a partition wall of loosely laid bricks to deflect the draught from each side of the kiln up into the top. The fire should be gentle at first and for 2 or 3 hours only near the openings. Then it should be extended right through. When white smoke changes to blue haze the bricks are dry and the fire can be made up fiercely and continued for about 3 days. Iron plates are used as dampers over the flue openings to regulate the burning. When the burning is finished all flue openings are closed up and the kiln allowed to cool for about 10 days. When unloading is finished the kiln can be charged and fired again. The disadvantages of this kiln are that burning is not always even, and more pila and jhama bricks are produced than in the next kind; and much heat escapes up into the air, and thus more fuel is used.

22. (2) *Bull's patent Trench Kiln.*—Used for burning bricks on a large scale. It is no good using this kiln for a small number of bricks, and for any number up to about 5 lakhs an Allahabad kiln should be used. The great advantage of a Bull's kiln is that it utilises escaping heat, and thus uses less fuel. Also the bricks are not exposed to sudden draughts, and burning is thus much more even, and the outturn of first class bricks higher. It is made in a trench varying from 12 to 20 ft. wide and 5 to 9 ft. deep, and running in a circle or with 2 long straight parallel stretches a short distance apart and connected at each end by sharp semicircular curves. The bricks in the trench are covered with ashes (at least 6 inches deep) to prevent escape of heat, and burning is carried on progressively round and round, so that heat is driven forwards all the time instead of escaping up through the top. Stacking kachcha bricks in advance of the burning and removing burnt bricks behind the fires is carried on continuously. The kiln is stacked in similar sections 17 to 25 ft. long, with a clear 6 inches opening at the end of each section for chimneys and dampers. In each section there are 6 furnaces across from side to side. At the top of the kiln 6 small feed holes are left over each furnace for top firing. Burning is started in the beginning from the bottom with wood fuel. Afterwards wood or coal is dropped in from the feed holes at the top. As burning advances the 2 chimneys and dampers are moved forward, Chimneys being kept about 2 Sections and dampers 3 Sections in advance of the burning. The outturn of bricks varies from $\frac{1}{2}$ to 1 Section a day, or from 5,000 to 15,000 bricks, according to the dimensions of the trench and the rate of burning. In one Section $23\frac{1}{2}$ ft. long, $13\frac{1}{2}$ ft. wide, and $5\frac{1}{4}$ ft. deep there are 12,000 bricks. If wood fuel is used 30 to 60 c.ft. are required per 1,000 bricks.

4. TILES.

23. A. *Uses.*—Used for roofing and flooring and for drains. Most tiles are earthenware, and made from clay in much the same way as bricks. There are also various patent tiles made of special materials, but only earthenware tiles will be dealt with here.

Tiles may be used if made and used locally. In this case local men will know all about them. It is generally inadvisable to use them if they have not previously been made and used in that place, unless special ready-made tiles can easily be imported, and there is some special advantage in using them. Tiles are made in much the same way as bricks, but being thin they require greater care in manufacture. Roof tiles generally vary from $\frac{1}{4}$ to $\frac{3}{4}$ inch thick,

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and floor tiles from 1 to 1½ inch. The earth should be stiffer, *i.e.*, of purer clay, and have very little sand in it, otherwise the tiles will be porous and brittle. Very thorough tempering is necessary. This is generally done first in a crushing mill and then in a pug-mill. For details see Roorkee Treatise on Engineering Section I, page 33 and plate IV.

B. *Classification.*—There are many kinds of tiles, some of the commoner being as follows:—

(1) Country tiles—
  (*a*) Pot tiles (Semi-cylindrical) used alone.
  (*b*) Pan tiles (flat with edges turned up) used in conjunction with pot tiles.
(2) Flat tiles—rectangular with 2 holes for nails and 2 projections for hooking on to battens.
(3) Allahabad tiles—something like pot and pan tiles, but thicker, larger and of superior make.

More details of these and other kinds of tiles will be given under buildings.

C. *Burning.*—Semi-cylindrical tiles are generally made as cylinders on a potter's wheel, and have a groove on each side of the cylinder so that after burning they can be split in two with a tap. They may also be moulded flat to start with and then made round on a wooden pattern. Tiles are burnt either in a separate kiln or at the top of a brick kiln. They need more gradual burning than bricks to prevent warping. As in the case of bricks, if a separate kiln is being used, the fires are gentle at first; then gradually increased till the flues are red hot, then no more fuel is given for 6 hours. Then the fire is increased till the flues are at white heat, and they are kept like this for 3 hours. Then no fuel is given for 6 hours, and again the fires are increased to white heat and kept like this for 3 hours. Then the flues are filled with fuel and entrances stopped up, and the kiln allowed to burn out. The whole process lasts about 72 hours. If the weather is windy, protect the kiln on the windward side, or the tiles on that side will be underburnt.

5. EARTH.

24. Earth is largely used for building walls for small and temporary buildings when cheapness is essential. Earth suitable for brick-making is the best. It should be tempered as for bricks and the wall be made of large lumps, which when dry will consolidate into a solid mass. The lumps should be laid in 9 inch layers and well beaten down with the hands. The wall should taper slightly, the basal width of an 8 ft. high wall being 2½ ft., and the top 1½ to 2 ft. The wall should be plastered over with clayey earth, and it may also be whitewashed. Heavy roofs should not be put on a building with walls of this kind.

When mud walls do not actually form part of a building, and have no regular roof over them, *e.g.*, courtyard walls, their tops should be protected from rain either with one or two courses of pakka bricks at the top, or with tiles or thatch.

6. LIME.

25. A. *Uses.*—A very important material, as it forms the chief ingredient of lime mortar (when used as mortar in masonry or as the matrix in concrete), of cement, plaster, whitewash, and distemper. These are all in common use in building construction.

B. *Origin and kinds of Lime.*—Lime is obtained from limestone or other forms of calcium carbonate (pure or impure). Calcium carbonate ($Ca\ CO_3$) may be almost pure (chalk and marble), but is generally mixed in varying proportions with sand, clay, magnesia and iron.

When limestone is heated or calcined $CaCO_3$ gives off its carbonic acid (CO_2) and leaves CaO, *i.e.*, calcium oxide or quicklime.

If water (H_2O) is then added it becomes $Ca\ (HO)_2$, *i.e.*, calcium hydrate or slaked lime, and in the process it effervesces and swells and gives out heat, and if in lumps it falls into a powder.

If slaked lime is mixed with water and made into a paste and left exposed to the air, it slowly hardens or sets. This is the property which makes it so useful for mortar, etc., as it is a substance which can be used soft to give bricks or stones an even bed by filling up their inequalities, and which will then harden and bind them together. Pure slaked lime from pure $CaCO_3$ is called *rich or fat lime*, and will not set throughout, but only on the surface, and will not set at all under water. It is not therefore much use for mortar, etc. If mixed with sand only it is called *poor lime*, and is much

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the same. But clay, and to a lesser extent magnesia and iron, make it set much better, and it becomes *hydraulic lime*, and the best qualities set even better under water than in the air. The slaking action of fat lime is very quick and violent, and it increases in volume 2½ times. As the proportion of impurities increases, the slaking action becomes slower and milder, and the increase in volume less.

26. Hydraulic limes may be classified according to the amount of clay they contain:—

(1) Feebly hydraulic. 5 to 12 per cent. clay. Slakes in a few minutes and fairly violently. In setting under water it is firm in 15 to 20 days and as hard as soap after one year.

(2) Ordinary hydraulic. 12 to 20 per cent. clay. Slakes after 1 or 2 hours and not violently. In setting under water it is firm in 7 days, and as hard as soft stone after one year.

(3) Eminently hydraulic. 20 to 30 per cent. clay. Slaking difficult and only after a long and uncertain period, and is very mild. Does not produce powder. In setting under water it is firm in one day, hard in 3 or 4 days, and very hard in one month.

27. Hydraulic lime may be made directly from a natural hydraulic limestone, which has a suitable mixture of clay, etc., in it, or it may be made artificially. There are 2 ways of making it artificially. Clay may be mixed with a fat or feebly hydraulic lime after slaking, and the mixture burnt a second time (twice-kilned lime). Or fat or feebly hydraulic lime may be made hydraulic and suitable for mortar by mixing it with powdered burnt clay—powdered burnt bricks, called surkhi, are generally used.

28. C. *Sources of lime*—

(1) Kankar. The commonest natural hydraulic limestone in the plains of Upper India. Contains 8 to 30 per cent. of clay, and generally makes excellent hydraulic lime, but some varieties contain too much sand and are not worth burning. It is advisable to test carefully before burning. The best kankar comes from deep beds and shows a bluish surface on fracture.

(2) Massive limestone from quarries. Generally yields fat lime, but is variable.

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(3) Limestone boulders from streams rising in hills containing massive limestone. They are the same as (2). Lime in Dehra Dun is generally obtained from these.

(4) Incrustations of calcium carbonate called calcareous tufa. Generally very pure fat lime. There are quarries of this near Lachiwala in Dehra Dun.

29. D. *Tests for an hydraulic limestone.*—Colour should be bluish grey or brown, and not white. It should only partially dissolve in diluted hydrochloric acid leaving a larger residue of clay and sand than purer limestone. A further rough test:—Put a few pieces 1½ inch diameter in an ordinary fire for 3 hours. To see if they are properly calcined put one piece in diluted hydrochloric acid; if properly burnt no effervescence takes place. Then take a properly burnt piece, powder it, and mix with one-third its volume of water and knead into a paste and roll into a ball in the hands. It will probably become warm (slaking action). When cool immerse it in water, and it will go hard if it is a good hydraulic lime.

30. *Rough analysis.*—Pound a sample of stone in a mortar and pass through a fine sieve. Put 150 grains by weight in a glass and pour diluted hydrochloric acid on it gradually, stirring it with a piece of wood. When effervescing ceases filter it through blotting paper and wash with a quart of water poured through the blotting paper. The residue will be sand or clay or a mixture of both. Dry it and weigh. The difference between its weight and the original 150 grains will be $CaCO_3$. Now wash the residue repeatedly to get rid of the clay, and the final residue of sand should be dried and weighed. If it is found that the original 150 grains contained say 110 grain $CaCO_3$, 10 grains clay, and 30 grains sand, the stone will give a fairly hydraulic lime. Less clay will give a poor lime.

E. *Lime Burning.*—To obtain lime, limestone is burnt in a clamp or kiln in much the same way as bricks.

(A) *Clamp.*

31. Generally circular, and about 16 ft. diameter with base at ground level, and about 12 ft. high.

If the fuel is wood or cowdung build up alternate layers of fuel and broken limestone. If the fuel is charcoal mix it well with the limestone. The whole heap has sloping sides and is plastered over with mud. It is fired in the same way as a brick clamp. This method is very wasteful of fuel, and the lime is of poor quality, as it gets mixed with fuel ash, if, as would generally be the case, the fuel is wood or cowdung. Charcoal does not leave much ash.

(B) *Kilns.*

32. (1) *Continuous kiln.*—For large quantities of lime. Built above ground with a circular wall. Alternate layers of fuel and limestone are packed inside and lit from below. As the lower layers are burnt, the upper layers sink down, and more fuel and stone are packed on top, and lime is taken out from below through a special opening. This process is continued so long as lime is wanted, and burning goes on continuously. The volume of fuel required is proportionately much less, and the quality of lime better than in other methods.

33. (2) *Intermittent kilns.*—This is the usual kind, and most likely to be used in the forest. The kiln is loaded with fuel and stone and burnt through. When cool the lime is removed, and if more lime is wanted, the kiln is re-loaded and burnt again.

There are many kinds. Two common types are as follows:—

34. (a) *Somewhat similar to the Allahabad brick kiln.*—Rectangular walls of stone set in mud starting from a few feet below ground level. Arched flue openings 1½ ft. high at intervals along the base of each side and opposite to each other. These flues are hollowed out in about 1 ft. × 1 ft. trenches across the floor of the kiln from one side to the other. The kiln is loaded as follows:—Flues are roofed over with large boulders, thus leaving passages below from one side of the kiln to the other for ventilation. Then a layer of wood fuel is laid over the whole floor of the kiln, and thereafter alternate layers of broken limestone and fuel up to the top of the wall. Limestone is generally piled up 2 ft. above the top of the wall. When coal is used the bottom layer of wood is 6 to 12 inches high and a layer of coal 2 to 3 inches immediately over it, followed by alternate layers of limestone 12 inches thick and coal 2 to 3 inches thick. The kiln is fired through the top of the flue holes at the side.

At one end of the kiln there is a wide opening from top to bottom for loading and unloading the kiln. This is blocked up during burning. Fuel may be entirely wood, or wood at the bottom and coal above.

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35. (b) *A simpler Type.*—Generally made in a sloping bank and of rectangular shape, the back and side walls without openings, and the front with one large and 2 small arched openings, the large one for loading and unloading and the small ones for setting fire to the kiln. The bank is first dug out to the required shape and the walls then built up. The top of the wall is generally at ground level at the back, and the bottom of the wall at ground level at the front.

The kiln is loaded either with all the fuel spread over the bottom and the stone above it, or with alternate layers of fuel and stone. The fuel is generally wood, but some coal may be mixed in the upper layers. If the kiln burns too quickly more limestone can be added at the top, and if it burns too slowly some stone can be removed from the top.

Similar kilns can also be built up on level ground.

36. *Notes applicable to both types.*—Walls must be thick, especially if built above ground, to prevent radiation of heat. Before every burning walls must be plastered with mixed cowdung and clay, and all cracks filled in. Time taken to burn is about 7 to 10 days, and to cool 2 or 3 days. When the lime is taken out, underburnt stone is put on one side and reburnt the next time, and the lime is sorted out as far as possible into 1st and 2nd qualities.

37. *Rough average figures of fuel required and outturn.*—For burning 100 c.ft. of limestone lumps 10 maunds coal or 32 maunds of fairly dry wood.

From 100 c.ft. stone outturn is 80 c.ft. lime.

1 c.ft. pure lime weighs 46 lbs., and 1 c.ft. hydraulic lime weighs 50 to 70 lbs., according to the amount of clay in it.

38. F. *Slaking, Grinding, and Storing.*—All lime should if possible be used not more than 24 days after removal from the kiln. If it cannot be used at once and has to be stored, it must be kept under cover and perfectly dry.

Pure or fat lime has to be slaked before use, but must not be slaked more than 2 or 3 days before it is required, unless it can be kept under water after slaking.

Impure or hydraulic lime often does not slake at all, and must be ground to powder or pulverised. This may be done by hand with heavy wooden beaters if the quantity is small, otherwise in a mill, which is generally a circular trough with a stone or iron

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roller, generally worked by bullocks. After pulverising it should be passed through a sieve with 8 to 12 meshes to the inch.

39. G. *Cement.*—It is in many respects similar to the best hydraulic lime, but contains 30 to 50 per cent. clay, never slakes when wetted after burning, and sets quicker and harder. It is used for wet foundations and works under water, for superior pointing and plaster, etc., and wherever great strength or rapidity of setting is necessary.

Natural cement is made in much the same way as lime by burning, special kinds of limestone containing 30 to 50 per cent. clay, and the burnt stone, which is brown, is pulverised. Natural cement stone is rare, especially in India, and artificially made cement is generally used.

Artificial cement is generally made from chalk and a particular kind of clay, which are ground in water, dried, and burnt in a kiln at a very high temperature, and then finally pulverised. The commonest kind is Portland Cement. In India artificial cement was until recently generally imported and English Portland Cement was generally used. Nowadays Indian made cements such as Katni Cement are more often used.

7. Uses of Lime.

40. A. *Mortar.*—A thick paste used (1) in between stones and bricks in stone masonry and brickwork, (2) in concrete mixed with broken stones or broken bricks, and (3) by itself as plaster or for pointing. The word ‘mortar’ is generally confined to (1).

(1) *Kinds of mortar.*—There are three kinds of mortar:—

(1) Mud mortar = clay and water, lime not being used. Used for inferior and temporary buildings, where strength is not required.

(2) Lime mortar = lime with sand or surkhi or with both (together with water). Used for all ordinary building work.

(3) Cement mortar = cement mixed with sand and water. Used in important building work where great strength or waterproof quality and quick setting is required.

The following notes apply to lime mortar except where otherwise stated.

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41. (2) *The quality and proportion of ingredients is important.*—Sand is mixed with lime for economy (lime alone being unnecessarily strong) and to prevent excessive shrinkage on drying. Fat or feebly hydraulic lime with sand only does not set properly. It must therefore be mixed with surkhi as well as sand, though if suitable sand is not available, surkhi alone will do.

42. *Proportions.*—For hydraulic lime=1 lime and 1 or 2 sand according to the strength of mortar required; 1 lime and 2 sand is sufficient for most forest works, but not for the bricks in a well that are under water.

For fat or feebly hydraulic lime=1 lime and $1\frac{1}{2}$ to 2 surkhi (1:2 is sufficient for ordinary forest works) or 1 lime, 1 surkhi, and 1 sand.

For cement=1 cement and 4 or 5 sand for ordinary purposes 1 cement and 2 or 3 sand where special strength is needed.

43. *Quality of Materials.*—Water must be clean and free from salt. Sand must be clean and free from clay and other impurities. The grains should be sharp and angular, and the sand the coarsest available. It must not be salty. If it contains lumps and stones it must be put through a sieve. If mixed with clay or earth, or if sea sand or other salty sand is used, it must be well washed. Surkhi is generally made by pounding burnt bricks to a fine powder. When bricks are not available, clay is made into round balls and burnt. Clays with a small proportion of sand (greasy to touch) are most suitable for this. Clays containing much lime (10 to 20 per cent.) are best if they are underburnt or ‘ pila ’, and those with little or no lime must be thoroughly burnt or ‘ pakka ’. Lime should be in a powder and must be fresh. Fat or feebly hydraulic limes must be freshly slaked unless they have been stored under water. For slaking place lime in a heap and add $\frac{1}{3}$ to $\frac{1}{2}$ its volume of water and mix thoroughly and leave till next day.

44. (3) *Mixing Mortar.*—If small quantities are required mix in shallow pits preferably lined with bricks, or on a clean platform.

If large quantities are required mix in a mortar mill (similar to that used for grinding lime).

Ingredients must be thoroughly mixed first when dry and then in a wet state, and the resulting mortar used as soon as possible; not more than 12 hours later if lime mortar, and not more than 20 minutes later if cement mortar.

45. (4) *Application of mortar.*—Must be used as stiff as it can be spread, though it must be moist enough to fill all the joints between the bricks or stones. Bricks or porous stones must be soaked in water for 2 or 3 hours before being used. In a dry state they would absorb a large amount of water from the mortar, which would then crumble and not harden properly. If the stone is granite or other non-porous kind it is sufficient to wet the surfaces just before laying. The work should be kept well wetted for 7 to 10 days after laying to prevent too rapid drying of the mortar, especially in hot dry weather. If it dries too rapidly it does not set so well. Mortar should never be more than $\frac{3}{8}$ inch thick between bricks or stones.

Mortar exposed to frost before it has set is seriously damaged. If frost is expected, either use quick-setting hydraulic mortar in the foundations and up to 3 feet above ground (where the frost is severest), or protect the work with grass or other covering. During severe frosts suspend the building work if possible.

46. (5) *Grout* is thin liquid mortar having very little strength. It should only be used when ordinary mortar cannot penetrate, *e.g.*, for deep and narrow joints.

N.B.—For other details, especially about cement mortar, see U. P. Forest Pocket Book, pages 275 to 282.

B. *Concrete.*

47. (1) *Ingredients and their necessary qualities.*—A form of artificial stone made by mixing lime or cement mortar (the matrix) with a hard material (whatever can be procured near at hand), *viz.*, broken stone or broken brick (the aggregate). They are mixed when dry and water is added to form a sort of conglomerate, which is then carefully laid in position and rammed hard to make it compact. Used chiefly for foundations of buildings or of bridge piers, and for floors and roofs.

48. For preparing *the matrix* the same rules as for mortar apply. Use matrix of lime mortar for ordinary works, and of cement mortar for those requiring great strength, quick setting, or waterproof qualities. For the *aggregate* a porous material is best such as broken brick, sandstone, or limestone, rather than a smooth one such as flint or shingle. There will then be rougher surfaces for the mortar to adhere to. The pieces must be angular and not

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rounded. If broken brick is used, the bricks should be well burnt or overburnt so as to be hard.

Size of pieces:—Average should pass through a $1\frac{1}{2}$ to 2 inch mesh. For important work $\frac{3}{4}$ or even $\frac{1}{2}$ inch gauge is used. For floors and especially for roofs a smaller size should be used than for foundations. For large masses of concrete, *e.g.*, in heavy foundations, large lumps of stone or vitrified brick can be put in, but they must be at least 3 inches apart and not near the surface, so that they can be entirely surrounded by cementing material. The size of the pieces influences the cubical contents of the interstices between them. These interstices have to be filled with mortar. To find out how much mortar is required, the contents of the void must be ascertained. To do this put a measured amount of aggregate (after wetting) in a watertight box, consolidate it, and then measure the amount of water required to fill all interstices. For aggregate of $1\frac{1}{2}$ to 2 inch gauge the average void per 100 c.ft. is 35 to 40 c.ft.

It is an advantage if the broken pieces are not all the same size, as this reduces the amount of the void, and thus of mortar required.

49. (2) *Proportions by volume.*—Lime Concrete average:—dry mortar 1, aggregate $2\frac{1}{2}$, *i.e.*, 100 c.ft. aggregate requires 40 c.ft. mortar.

If aggregate of $1\frac{1}{2}$ inch gauge is used this yields 110 c.ft. of finished concrete after mixing with water, laying, and ramming Cement concrete average:—dry mortar 3 (cement 1 sand 2) aggregate 4. To strengthen increase the proportion of mortar to aggregate, and in cement concrete also increase the proportion of cement to sand in the mortar. For floors and roofs use a stronger mixture than for foundations.

50. (3) *Mixing* (refers to both lime and cement concrete, except where otherwise stated).

Do not mix more than about 10 c.ft. at a time; but this depends on the amount of labour available for laying. Lime concrete must be laid within 15 minutes of mixing, and cement concrete at once. Measure the materials separately in 4-sided bottomless boxes 1 foot deep. Mix dry on a clean platform of concrete, brickwork, or wood. The aggregate must be soaked first, and if porous kept wet for 4 hours. Mix the mortar first in a separate heap, turning over at least 3 times till it is of a uniform colour. Then add the aggregate and mix thoroughly, adding the required water gradually from a watering can with a rose (if available) till the whole is of the required consistency, and turn the heap over at least 3 times until uniformly mixed.

The amount of water is important. Use the smallest amount necessary to ensure thorough mixing and to make it sufficiently plastic. The average amount of water for 100 c.ft. of lime concrete is 115 gallons. For mass concrete 100 gallons or less—this will be porous and not watertight, but will set quicker. For cement concrete more water is generally used, and the concrete is thus of a wetter consistency than lime concrete.

N.B.—For lime concrete water may be mixed with the mortar before mixing with the aggregate, though complete dry mixing is better.

51. (4) *Laying.*—After mixing lay in position at once. The concrete must not be thrown into position from a height, or the ingredients will separate in falling. It should be turned over into position gently.

For lime concrete:—Ram gently and steadily in layers not more than 6 inches thick. Wooden rammers may be used if the aggregate is brick, and iron rammers if stone. Continue ramming until the concrete has partially set (until a walking stick dropped endways on it from a height will rebound). Each layer must be thoroughly rammed, consolidated and watered before the next layer is laid. On the top layer all aggregate must be completely hidden—add extra mortar if necessary.

For cement concrete:—Compact it thoroughly till all ingredients have settled and surplus water has been forced to the top. Avoid excessive tamping. Laying should be finished 20 minutes after adding water in mixing. Lay in separate sections of not more than 10 feet length or width.

For both lime and cement concrete:—To prevent exposed surface from drying too quickly after laying, cover with sand and keep damp for 7 days for lime concrete and 10 to 14 days for cement; must be protected from frost if necessary.

N.B.—Do not lay lime concrete after 2 p.m., so that all ramming may be finished the same day. Cement concrete sets very quickly, and this precaution is not necessary.

52. (5) *Reinforced Concrete.*—A cheap and strong substitute for brick or stone work or for wooden or iron beams, etc.

The general principle is that the concrete is strengthened by having mild steel bars inside it. The steel bars are generally of round section of from $\frac{1}{4}$ to $1\frac{1}{4}$ inch diameter and of standard length.

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They must be soft enough to bend when cold, as they often have to be bent to a particular shape, and to join 2 lengths together the ends are bent round and hooked together and securely wired.

For circular structures such as wells circular steel hoops are used kept at the correct spacing by vertical bars to which they are wired.

The concrete is made of cement and sand matrix with aggregate of $\frac{1}{4}$ to $1\frac{1}{4}$ inch gauge in standard proportions. More water is required than for ordinary concrete, *viz.*, 130 gallons per 100 c.ft. concrete, so that it may be liquid enough to flow slowly into the forms (wooden framework in which the reinforced concrete is made). These forms or shutterings are made with their inside measurements corresponding exactly with the required dimensions of the concrete beam, etc., and are removed when the concrete has set. It makes removal easier if they are fastened together with screws, and also lined with paper or grease before the concrete is poured in. The reinforcement of steel bars is fitted together and then fixed in the forms, and finally the concrete is poured in.

C. *Plaster.*

53. A thin coating of mortar used to cover surfaces of walls, doors, water tanks, etc.

Cement plaster :—(1 cement 2 sand) used for lining reservoirs, water channels or tanks, floors of rooms (particularly bathrooms), etc., to make them watertight. Usual thickness $\frac{1}{2}$ inch.

Lime plaster for less important work, especially for walls of buildings to preserve exterior walls from the disintegrating effects of weather and to give interior walls a smooth finish.

It is like mortar, but less strength is required, and a larger proportion of sand or surkhi can be used.

Do not use very hydraulic lime, as unslaked nodules cause blisters. Slightly hydraulic lime with sand alone is the best. If fat lime with surkhi and sand is used, the surkhi must be from well burnt bricks, especially for external walls, as surkhi from pila bricks is not durable. The addition of chopped hemp or other fibre or some ox-hair in small quantities improves the strength and adhesive properties of the plaster.

Before applying plaster rake out the mortar joints to a depth of $\frac{1}{2}$ inch, clean the surface, and wet it thoroughly. Apply the

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plaster with a trowel and beat it well with a wooden mallet, sprinkling it during beating with water containing sugar (*gur*), which quickens setting and improves the quality of the plaster. Keep wet for 7 days.

One ½ inch layer is generally sufficient. If a second layer is to be applied, the first layer should be scratched across while moist to allow the second layer to stick to it.

For further details *see* United Provinces Forest Pocket Book, pages 295 to 298.

D. *Whitewash.*

54. A thin solution of slaked lime with the addition of gum and rice water to make it stick to the walls.

It is used over plaster on walls of houses—generally on interior walls and sometimes on exterior walls.

For full details *see* United Provinces Forest Pocket Book, pages 298 to 300.

Sometimes colour-washes are applied instead of whitewash. They are made by adding colouring matter to the whitewash.

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See United Provinces Forest Pocket Book, pages 300 and 301.

E. *Distemper.*

55. A special kind of paint used instead of whitewash. It is better than whitewash and can be washed, but is more expensive, and not generally used in forest buildings. If used, it should be bought ready mixed. *See* United Provinces Forest Pocket Book, pages 301 and 302.

8. *Metals.*

56. A. *Iron* is the most important.—Iron when first extracted from ores is called pig iron. It is not suitable for use and is refashioned into various forms, which differ in quality according to the amount of carbon they contain and the method of manufacture.

(1) *Cast iron.*—Obtained by remelting pig iron and running it into moulds of the required shape. Contains 2 to 5 per cent. carbon. It is cheap and strong, but brittle and liable to have flaws, and is not malleable. It is not much used in Engineering construction. One of its uses is for water pipes.

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(2) *Wrought iron.*—Obtained generally by remelting pig iron and refining it (removing carbon, etc.) and treating it in other special ways. Contains only 0·1 to 0·25 per cent. carbon. It is tough and malleable, and can be welded at white heat. Not much used in engineering construction, but is used by blacksmiths, and also for making ordinary and corrugated iron sheeting, which is much used for roofing, etc.

(3) *Steel.*—(A) *Hard Steel.*—Made from wrought iron by a special process which introduces more carbon and makes it harder. Contains 0·5 to 1·5 per cent. carbon. Used for tools and other articles requiring very hard surfaces. Cannot be welded or forged.

(B) *Mild or Soft Steel.*—Made from pig iron by special processes including melting and removing all carbon, etc., and then adding the required amount of carbon, *viz.*, 0·15 to 0·5 per cent.

The best for all engineering construction. It has many of the qualities of good wrought iron; *i.e.*, it is tough, malleable, and can be welded, and is much stronger and stands wear and tear better.

57. *Preservation of iron and steel.*—In damp air they rust and corrode very quickly. To prevent access of damp air cover with a non-corrosive layer.

Iron (especially sheeting) is often covered with a thin coating of zinc, and it is then called galvanised iron.

Coaltar laid on hot is a very good protection, but its black colour is often objectionable. Protection is usually effected where possible by paint.

58. *Other metals sometimes used.*

B. *Zinc.*—Light and durable. Used for galvanising iron sheets. Also for roof gutters and pipes.

C. *Copper.*—Very soft and malleable and does not rust. Too expensive to use much. Used for lightning conductors as it has a high electrical conductivity.

D. *Brass.*—An alloy of copper and zinc. Commonly used for screws, locks, hinges, and door handles, etc., for which it is better than iron as it does not rust.

E. *Lead.*—Very soft and plastic, heavy, and does not rust, but is not strong. Used for lining cisterns (water tanks), for roof gutters, joints of iron pipes, etc. It poisons water, and drinking water should not be allowed to come in contact with it.

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9. Timber.

59. Wood suitable for building and other engineering purposes is called timber. It is standing timber when part of the living tree, and converted timber when sawn into beams, planks, scantlings, etc.

60. A. *Characteristics of good timber.*—Heavy in weight in any one species (weight per c.ft. varies largely in different species). Smooth and hard appearance at a freshly cut surface; a dull chalky appearance is a sure sign of bad timber. Regular and even in growth (shown by annual rings when present). Straight in fibre, close-grained, free from large or dead knots, shakes, or any sign of decay. Colour uniform and not patchy. In coloured woods darkness of colour generally means strength and durability. Timber for beams and girders in roofs and bridges should be specially straight-grained. Timber which has to bear much weight or strain should only have small knots, which must be sound and not loose after conversion. In beams no knots more than $\frac{1}{4}$ the thickness of the timber should be allowed, and a cluster of knots must not be allowed. Maximum diameter for single knots usually 3 to 4 inches if near the end, and $1\frac{1}{2}$ to 2 inches if near the middle. There should be a similar rule for insect-borer holes, though timber suspected of having live borers should never be used.

61. B. *Sapwood and heartwood.*—Sapwood is much less durable than heartwood, and more liable to damage from insects and fungi. Do not use timber containing sapwood for important and permanent structures. If round timber is used for posts, piles, or girders, it should have all sapwood trimmed off.

62. C. *Seasoning.*—Newly felled trees are full of sap, and timber from them is called green. The sap must be expelled before the timber is used, or it will be liable to decay rapidly, will attract insects, and will often shrink and warp and crack after it is placed in position. Green timber should never be used in construction if it can possibly be avoided. If possible all timber should be felled and converted at least a year before required for use, unless it can be seasoned artificially in kilns.

Methods of conversion and seasoning are dealt with under utilisation.

63. D. *Causes of decay in timber.*—Timber will not usually decay if it is kept dry and put where air can get to it freely. It will not generally decay if continuously under water, but is weak-

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ened and becomes brittle. Decay is most rapid when timber is alternately wet and dry, or in contact with damp earth or masonry, and badly ventilated. Lime is very destructive to timber, and beams should not, if possible, be placed in direct contact with lime mortar. Posts, etc., in the ground are most liable to decay at and just below the surface of the ground.

64. (1) *Decay due to fungi.*—Chiefly from dry or wet rot. Dry rot usually attacks timber that is totally enclosed from the air. It spreads very rapidly. The best protection is to ensure free circulation of air round the timber. When timber is built into walls, a clear space should always be left round the sides, end, and top, and as little of the timber as possible should be in contact with lime mortar. Wooden floors should never be laid directly on the ground. Timber must always be stacked so that air can get freely to every part. Wet rot may start in green timber while still standing. In converted timber it will attack timber exposed to alternate wetting and drying, *e.g.*, timber in contact with the ground. The best prevention of wet rot is to use only well-seasoned timber, and to keep out further moisture by charring, tarring, or painting. It is important for timber to be well-seasoned and dry before doing this.

65. (2) *Decay due to insects.*—Chiefly from white-ants. It is probably impossible to secure permanent protection from them. It helps if all white-ants' nests in the vicinity of the structure are destroyed. Isolate timber in buildings from the ground by putting in white-ant proof courses in the plinth and beneath the floor. If only the heartwood of timber of certain species (teak, deodar, *sal*, etc.) is used, it will not be attacked by white-ants so often or so soon. Timber in contact with the ground should be treated with preservatives, such as creosote, which will lessen the danger of attack. Tarring will also have the same effect to a lesser degree.

10. METHODS OF PRESERVING OR BEAUTIFYING TIMBER AND MATERIALS USED.

66. All timber must be thoroughly dry. When the preservative provides a waterproof covering, *e.g.*, paint or oil, if applied when the timber is green, the sap is confined and ferments and produces dry rot. If an antiseptic is to be absorbed by timber, and there is sap and moisture in its pores, the antiseptic will not be absorbed properly.

67. A. *Charring.*—For preserving the ends of posts or piles to be placed in the ground. The ends are heated over a steady wood fire, turning them round till all surfaces are charred to $\frac{1}{2}$ inch depth. Then quench burning timber with water. It is a very rough method, and can only be done on a small scale.

68. B. *Tarring.*—With coaltar; is generally better, but does not last many years. Apply hot (nearly boiling) with a brush, or if possible dip the timber to be tarred into the coaltar. Heating makes the tar thin and it penetrates the timber more easily. Do not apply tar in cold or damp weather. The tar should be brushed well into all cracks. Tar is usually thinned with kerosene oil (4 tar 1 oil) or common country spirit (16 tar 1 spirit). 1 gallon of tar weighs $10\frac{1}{4}$ lbs. and is enough for 100 square feet of timber. A drum of tar usually contains 5 gallons and a barrel 25 gallons.

Iron exposed to the weather may also be tarred.

69. C. *Creosote.*—One of the best materials for antiseptic treatment. It is a dark brown thick oily liquid obtained from distillation of coaltar. The usual method of impregnation is to remove the air and moisture from the timber in an airtight vacuum by suction, and then pump in creosote under pressure and at a high temperature, so that it penetrates right through the timber. It is not washed out by rain and gives protection against dry and wet rot and insects. Timber may also be soaked in creosote in open tanks, alternately heating and cooling it, but this is not so effective. But it is more likely to be possible in the forest. Crude oil is often mixed with creosote (50 per cent.). This mixture is cheaper and nearly as good, and when heated it penetrates better. Creosote is expensive, and treating apparatus is not generally available in the forest.

70. D. *Solignum.*—A patented mixture containing various creosote oils, etc. Used for timber in buildings (doors, window frames, etc.) as a protection against white-ants. It is bought ready mixed and usually coloured like paint. It is heated and applied with a wire brush. 1 gallon is enough for 350 to 400 square feet. It is useful where coaltar or creosote would be objectionable.

71. E. *Oil.*—Oil is often applied to unpainted or unvarnished timber. It provides a waterproof covering, and is much cheaper than paint or varnish. Apply every year if the timber is exposed to the weather, and every 2 years if not exposed. Crude earth oil is the cheapest and is often used for the woodwork of buildings.

Heat till it flows freely and apply with a brush. Roof shingles should be dipped in boiling oil—4 gallons of oil for 1,000 hardwood shingles.

Linseed oil is also used for woodwork. It is more expensive, but more lasting, and can be polished. Raw linseed oil must be used if a polish is required, and frequent applications well rubbed in give a good polish. Boiled linseed oil is better for ordinary application. It dries quicker and is more weather-proof. A good mixture is 3 lbs. boiled linseed oil, 1 lb. turpentine, and 1 lb. beeswax. Heat the oil and wax in a vessel over a slow fire until the wax is melted. Add turpentine when the mixture has cooled, and apply in 2 coats.

N.B.—Boiled linseed oil is a dark yellow, and raw linseed oil is much lighter in colour.

72. F. *Paint.*—A very good preservative for timber and ironwork and improves its appearance, but is expensive, and for this reason is not often used in forest buildings. It is generally better to buy paint from a reliable firm than to buy ingredients separately and mix them. If the paint is too thick, use spirits of turpentine to thin it; but use it sparingly or the paint after application will be flat, *i.e.*, dull and not shiny, and will not be so durable. On timber exposed to the weather put 3 coats, and inside a building 2 coats. Paint should be laid on thinly and evenly, and each coat must be thoroughly dry before the next one is applied.

For full details of paints and painting *see* United Provinces Forest Pocket Book, pages 282 to 290.

73. G. *Varnish.*—A solution of resin in oil, turpentine, or alcohol. Used to brighten and protect painted surfaces, and is also often applied to unpainted wood (furniture, etc.), especially soft woods which cannot be polished properly. After application the solvent used evaporates and leaves a hard transparent film of resin on the varnished surface. Ordinary varnishes are not of much use if the wood is to be exposed to wet, especially hot water. Varnishes are generally bought ready prepared. The quality is very variable. They are classified according to the solvent used. Oil varnishes containing copal (resin of *Vateria indica*) or amber are the best, and can be used for out-door work. They are the most expensive.

Turpentine or spirit varnishes are cheaper and less durable, Preparation of the surface of the wood to be varnished is important, especially unpainted wood. *See* United Provinces Forest Pocket Book, pages 290 and 291.

11. MISCELLANEOUS MATERIALS.

74. A. *Putty.*—Used for fixing panes of glass in windows, etc., and for filling holes and cracks in timber. Made from whiting (finely powdered white chalk) and linseed oil and white lead mixed into a stiff paste. It should not be mixed more than a day before required, as if kept it goes dry and hard.

B. *Glass.*—Sheet glass generally used for doors and windows, etc. Plate glass is thicker and better quality glass and is not normally used in forest buildings. For the method of fixing glass in doors and windows (glazing) *see* United Provinces Forest Pocket Book, pages 292 and 293.

N.B.—Instead of putty narrow-strips of wood or metal are often used for fixing panes of glass in rough buildings in tropical climates, as putty is liable to crack and fall out.

C. *Pitch.*—A black shiny resinous substance obtained from the distillation of vegetable tar. It is used chiefly for caulking boats, *i.e.*, making the joints between the planks watertight. The joints are filled with hemp or other similar material, and the pitch applied hot in a melted condition. It sets hard when cold.

D. *Asphalt.*—Bitumen or mineral pitch. It is waterproof and easily applied in a melted state. It is useful for damp-proof courses in walls or over flat roofs.

12. NOTE ON TARS, CREOSOTES, AND PITCH.

75. A. *Dry or destructive distillation of wood.*—Burning wood without admission of air produces (1) charcoal (2) pyroligneous acid in liquid form. In the ordinary manufacture of charcoal the acid soaks into the ground and is wasted. If it is desired to utilise it, it is collected in special vessels placed underneath those in which the wood is burnt. When certain conifers are thus burnt (especially stump wood and knots) *vegetable tar* is obtained, the crude tar being mixed with the acids, etc. This tar can be purified by preliminary distillation, *i.e.*, heating it up to a certain temperature in closed vessels and driving off the vaporised acids and light oils and water. Further distillation at higher temperatures produces a residue of *pitch*. The distillates or distilled products are first water

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and light oils, then at higher temperatures middle oils, and at the highest temperatures heavy oils. *Creosote* is the name given to certain of these oils.

76. B. *By heating coal in closed vessels coaltar is obtained.*—It is usually a bye-product in the manufacture of coal gas, the product corresponding to charcoal being coke. When coaltar is distilled it produces at different stages as distillates first naphtha or naphthaline, then various oils including *creosote*, and the final residue is *mineral pitch.*

77. C. *Uses of the above products.*—Some of the uses of coaltar, creosote, and pitch have already been explained. The creosote generally used for antiseptic treatment is mineral, *i.e.*, obtained from coaltar, though true creosote is that obtained from wood. For caulking boats, etc., vegetable pitch is generally used. Mineral pitch (apart from that obtained from coaltar, which is often used for road surfaces) is found naturally in various forms called bitumen or asphalt; and these, or combinations of them with other mineral substances, are used for many purposes such as lining tanks, damp courses in walls, waterproof coverings for roofs, floors, etc., and for putting down on footpaths, etc., though not much use for the latter purpose in India, as it softens in hot weather when exposed to the sun.

For road surfaces coaltar by itself is the commonest material used—either for spraying the surface, or for mixing as a matrix with the upper layer of road metal (tar macadam). Mineral tar oils (not including naphthaline, light oils, and water) are also used mixed with 5 per cent. coaltar for spraying roads. Mineral pitch is also used mixed with tar oil to make it of a suitable consistency, being poured onto the loose road metal before consolidation (pitch-grouted macadam):

N.B.—Experiments with *chir* tar at Ranikhet for road surfaces have been made, but so far have not proved very successful, and it is not likely to compete with the mineral products.

III. CARPENTRY JOINTS.

1. INTRODUCTION.

1. Carpentry is shaping and combining pieces of timber to support weight or to form wood structures. Great care is necessary in design and formation of joints and fastenings so that the strength of the timber is maintained and is sufficient to withstand any weights or forces it must meet.

The following are the chief forces or stresses to which timber in construction is subjected :—

A. *Tension.*—Pulling or stretching lengthways from the ends. It tends to elongate and finally to tear in two.

Timber wholly in tension is called a tie.

B. *Compression.*—Crushing or pushing lengthways on the ends. It tends to shorten and finally to crush or buckle.

Timber under compression is called a strut or a brace. Posts and pillars are under compression.

C. *Transverse or cross strain.*—Pressure at right angles to the length, *e.g.*, a beam supported at the ends and with a weight downwards on to its centre. It tends to bend and finally to break across.

N.B.—When transverse stress is applied to a beam the upper part is in compression and the lower part is in tension.

D. *Shearing.*—Cutting or sliding; *e.g.*, cutting paper with scissors, or one beam sliding over another to which it is fastened.

This is not important except for, *e.g.*, bolts shearing through timber when placed too near the ends. It tends to distort and finally to cut in two.

2. THE CHIEF PRINCIPLES TO BE REMEMBERED WHEN MAKING TIMBER JOINTS AND FASTENINGS.

2. A. Arrange them so that the timbers to be connected are weakened as little as possible.

B. Make the abutting surfaces as nearly as possible at right angles to the pressure they have to resist. The parts which take the strain should be given the greatest possible effective surface.

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C. Fit each pair of surfaces carefully and accurately together to distribute the stress evenly; otherwise the timber tends to split owing to unequal pressure or tension in the fibres.

D. Make the joints as simple as possible with the fewest possible abutting surfaces. Complicated joints are less likely to be joined evenly and firmly, especially if skilled carpenters are not available, and they are more likely to decay rapidly.

3. Joints for lengthening timbers.

3. If sufficiently long pieces are not available, *e.g.*, for beams or rafters in roofs or for girders in bridges, two or more pieces may be joined together.

4. A. *Lap Joint.*—The end of one piece of timber is made to overlap that of the other. This is the simplest of all joints, easily made and strong, but is clumsy, and is only used in rough work and in temporary buildings. It is, however, the best way of joining beams in pile bridges when they are supported below the joint. The joint should be held by iron straps right round, or by bolts through the timber. Bolts are cheaper and neater, but straps are better because bolt holes weaken the timber.

5. B. *Butted and Fished Joint.*—This is the best method for general purposes. It is generally used for timber under compression, but is not good for timber under transverse strain. The ends of the two pieces are butted together and joined by fish plates of wood or iron bolted on opposite sides. The length of the fish plates should be at least four times the thickness of the timber, and six times for soft woods. The thickness of the plate if of iron should be $\frac{1}{4}$ to $\frac{3}{8}$ inch, and if of wood half the thickness of the timber. For joints under strong compression, *e.g.*, vertical posts or struts, fish plates should be placed on all four sides. The bolts should be placed zig-zag, *i.e.*, in two rows placed alternately, as this prevents the wood splitting and lessens the strain. Straps are sometimes used to avoid this danger, but they are not satisfactory, as they become loose if the timber shrinks. The total area of the bolts should be not less than one-fifth the area of the cross section of the timber.

6. C. *Scarf Joints.*—Used when both neatness and strength are required. Corresponding portions of the thickness at the ends of the pieces to be joined are cut away. The remaining parts are overlapped and secured by bolts, straps, or fish plates. The type of joint and fastening depends on the strain.

(1) To resist compression use a half lap or halved scarf joint, in which half the thickness of each piece of timber is cut away for a certain distance at the ends to be joined.

(2) To resist tension use a bevelled scarf joint, in which the joint running along the length of the timbers is not straight, but bevelled or at an angle.

These two are simple scarf joints and should, as a rule, be used over a point of support. They should generally be strengthened by fishplates prolonged beyond the joints, so that the end bolts can go through the whole depth of uncut timber.

(3) To resist transverse strain the joint is more elaborate. The top of the beam being under compression and the bottom under tension the joint is a combination of the first two, the upper half being square and the lower diagonal. A fishplate should be put below the joint to take tension. In the centre two wedge shaped hardwood keys are driven in from opposite sides to force the two pieces into close contact.

4. Joints in Timber Structures.

7. A. *Halving.*—A simple joint for wall plates or beams resting on other timber or on walls. Half the thickness of each piece is cut away. It may be used for two pieces in the same straight line, when it is similar to the halved scarf joint, or for two pieces at right angles. It is fastened with nails or wooden pins.

8. B. *Dovetail halving.*—Used to join a horizontal and a vertical timber at right angles, or a horizontal beam, *e.g.*, of a roof, and a diagonal rafter, *e.g.*, a collar beam and rafter. Cutting to a dovetail form makes the joint stronger than ordinary halving. It is fastened as in halving. The timber must be well-seasoned, as slight shrinkage makes the joints weak.

9. C. *Notching.*—This is a modification of halving. A small piece is cut out or notched, generally less than half the thickness, often out of only one of the pieces to be joined. Double notching is used when the notch must be deeper, and half of it is cut out of each piece. Notching is used for fastening floor joists to wall plates or roof rafters to purlins or wall plates. The fastening is by nails or spikes.

D. *Mortise and tenon.*

10. (1) *Ordinary mortise and tenon.*—Used for joining a vertical to a horizontal piece of timber. To form the tenon divide the end of the vertical piece of timber into three equal parts and cut out two rectangular pieces at the side, leaving the third piece in the middle. The mortise is a rectangular hole cut in the centre of the horizontal beam and into which the tenon fits. The mortise should be a little deeper than the tenon, so that the weight will be borne on the shoulders of the tenon and not on its end. The joint is fastened with a wooden pin.

11. (2) *Housed Tenon.*—This is a stronger form of the above joint, which is especially useful if the tenon has to be made in the horizontal timber, the whole end being let into the vertical piece, so that any weight to which the horizontal timber is subjected is borne by the whole thickness instead of by the tenon only.

12. (3) *Oblique Tenons.*—Used when timbers are inclined at an angle other than a right angle; *e.g.*, to join roof rafters to a tie beam, or struts or roof rafters to a king post. In the case of a king post truss oblique tenons are necessary in the following cases:—

13. (a) *To join the principal rafter and the tie beam.*—There are various ways of doing this. The tenon may be on the rafter, and the mortise in the tie beam should be as shallow as possible, so as not to weaken the tie beam. Another method is to make the tenon on the tie beam and the mortise in the rafter. The joint is strengthened either by means of bolts or straps, a good method being to use an iron heel strap round the foot of the rafter.

14. (b) *To join the principal rafter to the head of the king post.*—There are two methods. If the king post is big enough, make a square abutment the whole depth of the rafter, making the tenon on the rafter 1½ inches deep. But if the post is not big enough, the end of the rafter is cut, so that for only half its depth is the abutment square, *i.e.*, at right angles to the direction of pressure.

N.B.—In all the above forms of oblique tenon the upper part of the joint should be left slightly open to allow for the settling of the roof truss.

15. (c) *To join the struts to the base of the king post.*—Various forms at joint can be used. The best is a short stub tenon 1½ inches deep, which is sufficient to prevent the strut moving laterally, which is all that is required for pieces under compression.

N.B.—In a king post truss the tie beam and king post are in tension and the struts are under compression.

16. E. *Mitre Joint.*—Used to connect the struts to the straining beam in a strutted bridge. The joint is a butted joint, and so formed that the butted ends of both strut and straining beam are as nearly as possible at right angles to their length. The end of the strut is not quite at right angles to its length, so as to make the end of the straining beam more nearly at right angles to its length.

5. JOINTS IN PLANKING.

17. A. *Butted joint.*—The edges of the planks are planed true and placed together. This method is only used for rough work, because when shrinkage occurs an opening is left through the whole depth of the planks.

B. *Rebated joint.*—A rectangular strip is cut from the edge of each plank, and the edges thus overlap when fitted together. This joint prevents an opening through the whole depth of the planks.

C. *Rebated and filleted joint.*—A rebate is cut along the lower edge of each plank, and a strip of hardwood called a fillet is placed in this. The rebate is generally less than half the depth of the planks.

D. *Tongued and grooved joint.*—A tongue is made along the edge of one plank with a special cutting machine, and this fits into a groove cut along the edge of the adjoining plank. With this method hidden nailing is possible. There are several methods of cutting the tongue and groove.

6. FASTENINGS.

A. *Iron work.*

18. (1) *Bolts and nuts.*—These are used to fasten timber together and to make joints stronger. They are apt to weaken the timber by cutting through the fibres. Iron washers should be placed under bolt heads and nuts to increase the bearing surface, their diameter being about twice as great as that of the bolt head or nut, and their thickness $\frac{1}{3}$ the diameter of the bolt. The depth of the nut should be the same as the diameter of the bolt. When estimating the length of bolt required extra allowance must be made for the nut and 2 washers. When timber shrinks bolts become loose, and should, if possible, be retightened. In bridges, etc., where bolts and nuts are likely to be stolen, the screw thread

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on the protruding part of the bolt may be hammered over after fixing. This prevents the nut being unscrewed.

19. (2) *Straps.*—These are bands of wrought iron 1½ to 2 inches wide, and generally ¼ inch thick, but the dimensions depend on the quality of the iron and the strain upon it. They are often used instead of bolts, as they do not cut through and weaken the timber.

20. (3) *Plates.*—Straight iron plates used with bolts or screws to form fished joints and to strengthen timber under tension. Generally ⅜ to ½ inch thick. Bent plates are used to strengthen joints or to prevent lateral movement where timber is joined at an angle.

21. (4) *Nails.*

(a) *Cut nails.*—Stamped by machinery out of iron or steel plates.

(b) *Wrought nails.*—Made of wrought iron.

Cut nails are cheaper, but rather brittle, blunt pointed and with two parallel sides which are wider than the others. They should be placed with the parallel sides in the direction of the grain of the wood to reduce the tendency to split. Wrought nails do not easily break, and can be bent over if required to join two pieces of timber together. For fastening planks to beams, the length of the nails should be 2½ times the thickness of the plank.

(c) *Wire nails.*—Circular in section, very tough and strong. They are used in box making, etc.

22. (5) *Spikes.*—The same shape as cut nails, but larger (4 to 10 inches long) and used for heavy timber work. They are usually bought by weight—1,000 5-inch spikes or 330 7-inch spikes weigh 1 cwt. If used in timbers acting as ties they should be at least 9 inches from the end. Their heads should not be driven in flush with the surface, as this tends to break them off. When using spikes for joining two pieces of timber, holes slightly smaller than the size of the spikes should be bored with an auger through the first piece of timber.

23. (6) *Screws.*—They are used when the work may afterwards have to be taken to pieces, or where nails might split the timber. They are more secure than nails. Iron screws should always be greased, and in damp places copper or brass screws are used to prevent rusting and difficulty in withdrawing.

24. (7) *Dogs or dog-irons.*—Short pieces of wrought iron with both ends pointed and bent over at right angles to form teeth.

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Length 9 to 18 inches with teeth of 3 to 8 inches, and ½ to ¾ inch square section. Used for fastening frames of heavy timber, specially in temporary bridges. They should be used on both sides of the frame. The teeth should not be driven within 3 inches of the edge or within 4 inches of the end of a piece of timber.

25. (8) *Drift Bolts.*—Pieces of round or square iron without heads or points, driven like spikes, but into holes previously bored. They are better than dogs for permanent work, and are much used in bridges for fastening timbers and preventing lateral movement. The hole for the bolt should be ⅘ the diameter of the bolt, and should be drilled right through the upper timber and into the lower one for ¾ the distance the bolt will finally penetrate. For joining 12 inch timbers the bolt should be 20 inches long. The diameter is generally ¾ inch for bridge work.

B. *Wooden Fastenings.*

26. *Trenails.*—Large wooden pins made of straight-grained hardwood such as teak, or from culms of bamboos such as *Dendrocalamus strictus*. They should be split, and are usually square or polygonal. They are used where iron nails may rust, and also to look nice in carpentry work, and in timber framing, *e.g.*, to secure mortise and tenon joints. Holes are bored before driving them, generally a circular hole for a square trenail and of a diameter equal to the side of the square.

IV. BUILDINGS.

1. Choice of Site.

1. The following is a summary of the important points to consider before choosing the site of a building:—

(1) Water supply. Good water must be available in sufficient quantities either from a well or running stream or canal or a spring.

(2) Good drainage.

(3) Site should be slightly raised above the surroundings and have a good view if possible.

(4) Aspect in relation to sun or prevailing winds, etc., *e.g.*, in hot climates it is often advisable to have the building facing north-east or east to avoid the hot afternoon sun on the front or to get cool breezes; while in cold climates a south or south-west aspect will get the full benefit of the sun.

(5) Accessibility.

(6) Convenience for its particular purpose, *e.g.*, a Range Officer's or Forest Guard's permanent quarters should be as near as possible to the centre of his charge, but should nevertheless be near a village both for obtaining supplies and for social reasons.

(7) If near to a river or stream it should not be too near the banks if they are liable to erosion, or if the river may change its course. If in this case there is a village near by, site it upstream from the village.

(8) Type of soil and subsoil is very important and is discussed under foundations.

2. Preparation of Site.

2. The following points should be attended to:—

(1) All tree stumps and rubbish should be removed, and dense trees and undergrowth should be cleared for a considerable distance round the site to lessen the danger of fire

in the dry weather and dampness in the monsoon and to prevent the harbouring of mosquitoes. It will, however, be advisable to leave some scattered trees in the compound for shade.

(2) If white ants are prevalent, any nests on the site and for about 20 ft. round should be destroyed. If the queen ants (thick white grubs 2 to 3 inches long) can be destroyed, ants will be less likely to come back. It may be necessary to dig down some way to find queens.

(3) Get rid of any stagnant water in the neighbourhood. It is unhealthy and mosquitoes will breed in it.

(4) Special drainage is not generally necessary if the site is well chosen. But it may be necessary to divert surface water from higher adjoining land by making drains round the boundary of the compound, and of course surface drains round the buildings are always advisable to collect and carry away rain water.

3. FOUNDATIONS.

A. *Definitions.*

3. The term foundation will be applied only to the lower courses of a building below ground and up to plinth level. The plinth is that portion of the wall from ground level up to floor level, and plinth level is the top of the plinth. The foundation bed is the artificially prepared surface on which these lower courses rest.

B. *Foundation Bed.*

4. (1) *General Principles.*—The strength and durability of a building depends on the character of the foundation bed, and it is very important. A solid base is required for a building so that if possible no movement, or at any rate no unequal movement, shall take place after its erection. This base should be wide and hard enough to bear the pressure of the building on it with the minimum of yielding. It should also be deep enough below the surface to prevent rain water penetrating and uncovering or softening it, or frost disintegrating it. All buildings of coursed masonry will settle to a certain extent, and almost all soils will be more or less compressed under the weight of a building. It is thus impossible to prevent all settlement, but the settlement must be uniform; *i.e.*, not an unyielding, but an uniformly yielding foundation bed, so that the building may not settle unequally and thus crack or fall down. Two important principles are firstly to distribute the weight of the building evenly over a large area of bearing surface, and secondly to prevent the lateral escape of the supporting material.

5. (2) *Choice of Foundation Bed.*—In order to be sure that the foundation bed will be firm enough it is necessary before choosing the site to find out the nature of the subsoil, and if it is suitable. If this is not known for certain, a pit should be dug.

There are three main classes of soil from the point of view of firmness:—

(*a*) Incompressible, and do not yield laterally—solid rock, compact stony soil, and hard clay which can only be broken by blasting or with a pick-axe.

(*b*) Incompressible, but yield laterally—pure gravel and sand.

(*c*) Compressible—all ordinary earths and ordinary clay and marshy soils. Most clay and common earths are only compressible to a certain extent. Others are almost fluid and yield easily in any direction.

6. General rules for choice of foundation bed are as follows:—

(*a*) Solid rock is the strongest, but often expensive to prepare. Thickness must be sufficient. Heavy buildings must not be built on a thin seam of rock overlying soft earth. If necessary it may be tested by a trial weight at least twice that which it will have to bear permanently.

(*b*) Sand and gravel are good. Drainage is good, but lateral escape must be prevented.

(*c*) Clay should, as a rule, be avoided. Drainage is bad, and it is difficult to prevent the dangers arising from exposure to weather influences.

(*d*) Ordinary compressible earth is generally all right, if not too clayey and not too wet and marshy.

(*e*) No buildings should be erected on recently deposited earth, *i.e.*, on earth deposited a year or less previously.

(*f*) Foundations of the same building should never be on two different types of soil, or uneven settlement will result.

(*g*) Always avoid access of water to the foundation bed.

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7. (3) *Preparation of Foundation Bed.* (*a*) Rock.—Remove upper stratum if weathered or otherwise injured. Prepare the surface of the rock by levelling it and filling up inequalities with concrete. If fissures or holes are too large to fill up, arches may be made across them.

(b) *Stony earths and hard clay.*—Dig a trench to receive the foundation. This must be deep enough to reach compact soil not injured by the action of frost or heavy rain. If the soil is clay, it should be covered with the foundations as soon as possible. If the clay is left exposed for long it will disintegrate. The clay should be covered with a layer of concrete unless it is certain that the trench is deep enough to prevent the contraction and expansion of the clay owing to alternating drought and rain, or heat and cold. Drainage is also advisable to prevent surface water getting to the foundation bed.

(c) *Compact gravel and sand.*—The foundation bed should be made deeper and wider than for other soils. If there is no liability to lateral yielding procedure is the same as for stony earths. If lateral yielding is possible sheeting piles should be used to confine the bed laterally. These are flat piles varying from 2 to 12 inches thick and any convenient breadth, sharpened at the lower end, and driven in successively edge to edge to form a vertical 'sheet'. They may be of wood or of iron.

Care should be taken not to make deep excavations anywhere near the foundations, and any existing holes should be filled up.

(d) *Compressible earths.*—In ordinary clay or earth a trench of suitable width and depth should be dug, and a bed of concrete at least 12 inches thick should be laid. In wet or marshy soils various methods are employed to secure a solid and dry foundation bed, *e.g.*, draining springs, driving piles down to a firm stratum and building on a platform erected on the piles, etc. Such soils should be avoided, and it is seldom necessary to choose a site on wet or marshy soil.

8. (e) *General rules for the excavation of the foundation bed.*—Before excavation the position of trenches must be carefully marked with pegs and string. Foundation bed must be perpendicular to the direction of pressure, *i.e.*, for perpendicular walls it must be horizontal. Levels should be taken, and on sloping ground excavation be done in steps, called benching out. Say the desired depth is 2 ft. Then commence at the lower end and dig to 2 ft. depth.

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If the steps are say 6 inches high, then proceed up the slope till the trench is 2 ft. 6 inches deep, when the level should be raised by 6 inches so that the trench is again 2 ft. deep. Then proceed as before. Great care should be used in excavating. If the trench is dug too deep by mistake, it must not be filled up to the correct level with earth, or the foundation bed will not be firm, but it must be built up with masonry or concrete. In ordinary soils when excavation is complete the bottom should be tested with a strong wooden beater to detect concealed hollows, especially where white ants exist. If weak spots are found, they must be dug out and filled up with concrete to the level of the bottom of the trench.

C. *Foundations.*

9. (1) *Depth, Breadth and Form.*—For depth and breadth of foundations no definite rules can be given. They depend chiefly on the character of the foundation bed and on the size and weight of the building. The depth in ordinary earths should be at least 1 ft. below ground, and may be as much as 6 ft. Average is 2 to 3 feet. The breadth will normally depend on the thickness of the walls above plinth level, and partly also on the nature of the foundation bed and the weight of the building. Depth and breadth are generally greater for exterior walls than for interior ones, but this depends chiefly on which walls bear the most weight. Starting from the main wall above plinth, the thickness of the plinth and foundation walls must increase in successive steps downwards. The step formed on either side by the increased width is an offset. This is normally ¼ brick wide and not more than 3 inches, so that where stretchers are used in that course, no stretcher is left uncovered. The depth between one offset and the next should never be less than 2 courses, *i.e.*, about 6 inches. The number of offsets depends on the increase in width desired, but there must at least be an offset at floor level (top of plinth), and at ground level (bottom of plinth), and if there is a concrete footing or other artificial foundation bed below the foundation wall, it must be at least 1½ times as wide as the foundation wall. As a rule the concrete footing should be 6 inches deep per 10 ft. height of wall. The plinth may be any height, but at least 12 inches, and in sites inclined to be damp should be considerably more.

10. (2) *Earth filling.*—When the building has reached plinth level, the space between the masonry and the side of the trench should be filled in with earth, watered, and rammed in 6-inch courses. The earth used should be clayey or loamy, and if it is damp no water should be used. In any case very little water is necessary.

When the main walls are 2 ft. above plinth level, if the floor is to be of concrete or other similar material the inside space should be filled up nearly to the top of the plinth with earth in 9-inch courses, watered and rammed. This is not necessary for plank floors. On completion of the building the ground for 50 ft. all round should be dressed and given a gentle slope outwards of 1 in 40. The plinth should also generally be protected by a layer of rammed broken stone or brick at least 3 inches deep and for a width of 3 to 5 ft. all round the building, and sloping down from the plinth at a slope of at least 1 in 30. The surface should, if possible, be well rammed until it is like the surface of a metalled road.

4. WALLS.

A. *Thickness of Walls.*

11. Walls are often made thicker than is necessary. In brick masonry a wall of 1st class bricks in lime mortar in single-storied buildings should not, as a general rule, be made thicker than 1½ bricks (13½ inches). But if the building has an exceptionally heavy roof the walls may be 2 bricks thick (18 inches) to be quite safe. Inner partition walls need not be more than 1 brick thick, and never more than 1½ bricks thick. In a large double-storied building the lower story walls may be 2½ bricks thick, the upper story walls being 1½ to 2 bricks thick according to the weight of roof. As a general rule, walls with lime mortar should be made as thick as $\frac{1}{16}$th their height to the nearest half brick for main walls, and less for partition walls, or other walls bearing less weight. For stone masonry 15 inches is enough for the main walls of single story buildings.

12. No wall should be more than 50 ft. long without being supported by cross walls or buttresses. If a wall is being built round a compound (a pardah or enclosure wall), it should have buttresses at intervals, *e.g.*, a wall 1½ bricks thick may have buttresses 2½ or 3 bricks thick at intervals of 20 ft., the buttresses being about 4 ft. long.

B. *Scaffolding.*

13. Temporary erections of timber or bamboos, which support platforms close to the work. When workmen cannot reach the work from the ground they stand on these platforms. If holes are left in brick walls to support the transverse poles, headers and not stretchers should be left out, and when the scaffolding is being removed a brick should be inserted carefully in each hole. The poles should not be built into the wall, as is sometimes done to make them firmer, as their removal then damages the wall. Scaffolding for stone masonry is not generally supported in the wall, but is made with 2 rows of standards so as to stand independently.

C. *Timber embedded in walls.*

14. To prevent decay an air space of about $\frac{3}{4}$ inch must be left on both sides and on top and at the end. The best way is probably to have wall plates of stone or reinforced concrete above and below the insertion of the beam.

Similarly wall plates, which are beams placed on the tops of walls to receive the ends of roof timbers and to distribute the weight, may with advantage in cases where they have to be built into the wall be replaced by slabs of stone or reinforced concrete.

5. MASONRY.

A. *General Rules.*

15. (1) Build up the walls uniformly so that no part is at any time more than 3 ft. above the rest, or settlement may not be uniform and cracks may appear.

(2) If for any reason this cannot be done, and one part has to be built up in advance of another, build up in steps and not straight up. If a long time elapses before the rest is built up and joined up and the mortar has set, rake out the joints so that the new mortar may go into them and the connection be stronger.

(3) When work is left off at night, lay a fillet of mortar $1\frac{1}{2}$ inches high round the edges of the last course laid, and fill it with water.

(4) Soak bricks and porous stone in water for at least 3 hours before laying and keep all masonry wet for at least 7 days after completion. This prevents the water from being drawn out or

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evaporated from the mortar too fast, which would prevent it setting properly and would reduce it to powder.

(5) In brick masonry lay bricks with the frog uppermost. This ensures the frogs being filled with mortar and strengthens the wall.

(6) Fill all joints and other spaces between bricks or stones completely with mortar.

(7) Mortar joints usually $\frac{1}{4}$ inch thick, and the maximum should be $\frac{3}{8}$ inch (except in some of the rough kinds of stone masonry).

B. *Brick Masonry.*

16. (1) *Definitions.*—There are 3 kinds of brick masonry:—

(a) *Pakka.*—Burnt bricks in lime mortar.

(b) *Kachcha-pakka.*—Burnt bricks in mud mortar.

(c) *Kachcha.*—Sun dried bricks in mud mortar.

Pakka masonry should be used whenever funds permit. But kachcha-pakka is frequently used if economy is necessary, but only above plinth level. It is best if it is only used in interior walls, though it is sometimes used in exterior walls in unimportant buildings. Similarly if funds do not even permit of the use of kachcha-pakka masonry, kachcha masonry is sometimes used above plinth level, but it should never be used when the walls have to support considerable weight.

17. (2) *Bond.*—In all masonry correct bond is very important. Bond is the arrangement of bricks in each course, and of each course on the one below it. Bricks must break joint and have no continuous vertical joints, which are called 'splits'. Good bond ensures distribution of weight, preventing unequal settlement and cracks, and also binds the wall together lengthways and crossways.

There are 2 main systems of bond:—

English bond has alternate stretcher courses and header courses. Flemish bond has alternate stretchers and headers in each course. Both these would give splits if employed without closers, which are half-bricks ($9 \times 2\frac{3}{16} \times 2\frac{3}{4}$ inches), and are always put next to the 1st header in every course in which a header comes 1st, *i.e.*, in every other course. It is especially important to keep the vertical joints of equal thickness and down to $\frac{1}{4}$ inch, otherwise 2 headers will occupy a little more space than one stretcher, and correct breaking of joint will be lost, and splits will occur unless another closer is introduced. This should, if possible, be avoided.

Flemish bond is supposed to look nicer on the face of the wall, but English bond is better and stronger, especially in thick walls, and should always be used. Another disadvantage of Flemish bond is that where offsets are necessary stretchers have to be used. The wall is stronger if headers only are used, and in English bond a header course should always form the offset. Two other systems of bond may be mentioned:—

> Heading bond with headers only, used for turning sharp curves such as in wells and small arches. Closers must be used to preserve good bond.
>
> Stretching bond with stretchers only used in exceptional cases if half-brick thick walls have to be built. Use half-length headers at the end of alterate courses.

18. (3) *Special Rules for Kachcha-pakka brick masonry.*—Foundations and plinth and all arches should always be built with pakka masonry. It is also advisable to use pakka masonry for door and window jambs and for the top 12 inches or so of exterior walls. If kachcha-pakka is used for exterior walls they should be plastered or pointed with lime mortar as a protection to prevent the kachcha mortar from being washed away by rain. Before laying the bricks they need only be dipped in water, and the top courses of unfinished work need not be covered with water.

19. (4) *Calculation of the number of bricks required for a work.*—The statements on page 304 of the U. P. Forest Pocket Book in this connection are misleading. For bricks of standard size ($9 \times 4\frac{3}{8} \times 2\frac{3}{4}$ inches) 100 c.ft. brickwork with bricks laid dry requires 1,596 bricks, and allowing $\frac{3}{8}$ inch mortar joints requires 1,293 bricks, and allowing for breakages in transport a safe allowance is 1,400 bricks. Thus if buying bricks ready burnt allow 1,400. When calculating the number to be burnt wastage in kilns must be allowed for. Probably only 50 to 60 per cent. of bricks moulded will turn out first class, and 20 to 30 per cent. second class. Thus to get 1,400 first class bricks burn 2,500 if a good outturn is expected. This will also, of course, produce, say, 700 second class bricks, and the balance of 400 will be third class or useless. To be absolutely safe burn 3,000, 50 per cent. of which will be 1,500. This will allow for all eventualities.

C. *Stone Masonry.*

20. When stone is easily obtainable, stone masonry may be cheaper than brick masonry, but the work requires greater skill and more supervision.

(1) *Classification.*—It is classified according to the way stone is prepared and laid, a general distinction being that regular coursing has stones in each course of equal thickness, and random coursing has stones in each course of unequal thickness. Random rubble may have no courses at all.

(a) *Ashlar.*—Stones are dressed on all faces in rectangular blocks of definite size, and laid in courses of uniform depth, usually not less than 1 ft. or more than 2 ft. It is usual to lay alternate headers and stretchers as in Flemish bond in brickwork. This is stronger than any other stone masonry, but owing to the careful dressing of the stones it is very expensive, and only used in special cases.

(b) *Block-in-Course.*—Similar to ashlar, but the stones are smaller, and dressing of stones a bit rougher. Courses 7 to 9 inches deep.

(c) *Coursed rubble.*—Stones are squared on the outside face and for a short distance back. They are laid in courses of a height which may vary in the same wall, generally from 6 to 9 inches, all stones in each course being of the same height.

(d) *Random squared coursed rubble.*—Stones are cut as in coursed rubble, but stones of varying size are put in each course.

(e) *Random rubble.*—Stones are roughly dressed, and generally irregular and not rectangular. It may be built in courses of 1½ to 3½ ft., or without courses. In the interior of the wall the spaces in between the large stones are filled with small stones embedded completely in mortar. This is the weakest type of all, and if used alone is only used as a rule for fencing walls.

(f) *Combination of ashlar or block-in-course or brickwork with rubble.*—The corners and sides of openings are built of bricks or of ashlar or block-in-course masonry, and the intervening walls of rubble. It may also be strengthened by string courses of ashlar or block-in-course or bricks running right across at intervals. This looks better and is stronger than rubble alone. It is commonly used in Dehra Dun.

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(g) Ashlar or block-in-course masonry on the face, or on both face and back of the wall, with rubble in the rest of the wall. The bond connecting the two is in this case important.

(h) *Dry rubble.*—All kinds of rubble masonry can be built without mortar. This is useful for retaining walls, small dams or culverts, etc., especially in hill roads. It cannot support a heavy weight. The strength depends chiefly on careful laying and correct bond.

21. (2) *General Rules for stone masonry*:—

(*a*) For all types of rubble use the largest stones for the lower courses.

(*b*) Size and shape of stones:—

For ashlar and block-in-course for soft stones the breadth should be at least equal to but not more than twice the depth. For hard stones it may be 3 times the depth. The length for soft stones should be not less than twice nor more than 3 times the depth. For hard stones it may be 4 or 5 times the depth.

For rubble similar rules apply, but the length need not be more than $1\frac{1}{2}$ times the depth.

(*c*) Stones should always be laid on their widest bed and not on edge or end. Stratified stones should be laid on their natural bed, *i.e.*, with strata at right angles to the direction of pressure.

(*d*) If boulders are used they must be roughened by knocking off some of the smoothed surfaces.

(*e*) Bond should be preserved on the same principles as in brick-work, *i.e.*, no through vertical joints should be allowed. Through headers or ' throughs ' should extend from face to back of the wall at regular intervals. But if the wall is too thick for this, ' binders ' should be used, *i.e.*, 2 headers from opposite sides overlapping 6 to 9 inches in the centre, or overlapping an interior header. The total superficial area of headers in the face of the wall should be for ashlar and block-in-course $\frac{1}{3}$ total area, and for rubble total area. Headers should never be placed directly above each other.

(*f*) The thickness of mortar joints:—

Ashlar and block-in-course $\frac{1}{8}$ inch if possible, though they generally have to be a bit thicker.

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Coursed rubble and random squared coursed rubble $\frac{1}{4}$ inch. Random coursed rubble $\frac{1}{2}$ inch. Random rubble not more than 1 inch.

D. *Arches.*

22. (1) *Definitions.*—An arch is specially arranged masonry, usually curved, and built across a space to support the weight of masonry, etc., above it. The terms applied to the parts of a typical arch are:—

Springing—the lowest extremity of the arch.

Intrados—the under side of a large arch (*e.g.*, of a bridge).

Soffit—the under side of a small arch (as generally in buildings).

Span—the horizontal distance between the springings.

Rise—the vertical height from the springing level to the highest point of the intrados or soffit.

Voussoir—the wedge-shaped bricks or stones which make up an arch.

Key—the central voussoir at the crown or top of an arch.

Skewback—the upper surface of the abutment or pier from which the arch springs, and so formed as to radiate from the centre of the arch.

Haunch—the lower half of an arch from the skewback to a point half way to the crown.

Extrados or back—the upper side of an arch.

Spandrel—the space over the extrados and under the horizontal line drawn through the crown.

Abutments—for a single arch are the structures which support the arch and from which it springs. For a series of arches the structures which support the ends of the series.

Piers—the intermediate supporting structures between the abutments.

23. (2) *Chief types of arches.*—There are many types of arches, but the following 3 are the only ones likely to be required for forest buildings or bridges:—

(*a*) Segmental forming an arc of a circle, the angle included by the radii from the skewbacks being less than 180°,

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and being usually about 90°. This is the commonest type.

(*b*) Semicircular. This is the strongest type for bearing great weights, but if unloaded it is apt to collapse owing to pressure from the crown thrusting the haunches upwards so that the crown falls in.

(*c*) Flat. Used over door or window openings instead of wood or stone or concrete lintels. It must have a segmental or semicircular relieving arch over it.

24. (3) *Proportions for the parts of an arch.—Rise* for segmental arches—the best is $\frac{1}{5}$th the span, which is the proportion when the angle between the radii is 90°. The rise for semicircular arches is, of course, $\frac{1}{2}$ the span.

Thickness of arch.—A general rule is as follows:—

(*a*) At the crown—

For single segmental arch $\sqrt{0{\cdot}12 \text{ radius}}$.

For segmental arches in series $\sqrt{0{\cdot}17 \text{ radius}}$.

For single semicircular arch $\sqrt{0{\cdot}2 \text{ radius}}$.

For semicircular arches in series $\sqrt{0{\cdot}25 \text{ radius}}$.

For concentric brick rings add 12 per cent.

(*b*) At the haunches—

50 per cent. more. This rule is not generally applied to small arches.

In practice the following thickness may be used for brick arches:—

Small arches up to 6 ft. span should be $1\frac{1}{2}$ bricks ($13\frac{1}{2}$ inch).

It is safer to make no arches less than this, though up to 4 ft. span they may be made 1 brick thick if they have not much weight to bear. From 6 ft. to 36 ft. should be 2 bricks thick (18 inch) at the crown.

The thickness should be increased by $\frac{1}{2}$ brick for every 8 ft. of span above this. Thus for 70 ft. span (the maximum likely in India) the thickness will be 4 bricks.

In small arches up to 15 ft. span the thickness at the haunches need not be increased. For spans from 15 to 20 ft. it is only necessary to increase by $\frac{1}{2}$ brick.

Thickness of pier.—$\frac{1}{7}$ the span.

Thickness of abutment.—$\frac{1}{5}$ the span, but must not be less than $1\frac{1}{2}$ times the thickness of the arch.

In a long series of arches every 4th or 5th pier should be as thick as an abutment.

25. (4) *Shape and arrangement of bricks and stones in arches.*—It is very important for the joints to radiate correctly from the centre from which the arch is constructed.

(a) *Brick arches.*—Arches are usually of brick where bricks are obtainable. They are called plain or rough when ordinary rectangular bricks are used, and cut or gauged when bricks are cut and rubbed into the necessary wedge-shape. The best method of all is to have specially moulded wedge-shaped bricks. Ordinary bricks are often used where good appearance and special strength are not necessary, but should only be used for arches of small span. Cut bricks are better and look nicer, but cutting makes them less weatherproof. For important work specially moulded bricks should be used.

When using ordinary bricks joints should not be continuous through from the soffit to the extrados, but the arch should be built in a series of separate concentric rings 1 or $\frac{1}{2}$ brick thick. This, especially the latter, avoids too thick mortar joints at the upper end of the joint, and a certain amount of bond is preserved, because in each ring the lower edges of the bricks are practically touching, and thus each ring will have more bricks in it than the ring below it. In arches of concentric rings a strengthening is sometimes introduced at intervals in the form of keys made of blocks of bricks of a different bond, usually specially cut or moulded wedge-shaped bricks. Blocks of stone can also be used.

When using cut or specially moulded wedge-shaped bricks the arch should be built so that the radial joints are continuous from the soffit to the extrados, and each course is properly bonded in English bond as in ordinary brick masonry.

(b) *Stone arches.*—Stones are cut to the correct wedge-shape. The length of each stone will equal the thickness of the arch up to 15 inches. Above this 2 stones may be used. The same principles for bond apply as in other stone masonry works.

26. (5) *Construction of an arch.*—It should be built up evenly from each side. Once the work has started it should be finished as soon as possible. The last thing to do is to drive the key firmly into position with a wooden mallet. The mortar used must be of finely ground lime or of cement. When specially moulded bricks or specially cut stones are used it is important to make them the correct shape. For a stone arch first lay out the arch full size in elevation on a levelled surface with the joints marked. Templets or moulds are then made (of tin or zinc) of the correct size, and the stones cut to fit them.

27. (6) *Centering.*—This is a framework erected to support the arch while it is being constructed. Its upper surface must be the correct shape of the soffit, and it must be strong enough to bear the weight of the arch. It is generally made of wood, the upper rounded part over which the arch is built having wedges driven in between it and the supporting posts. A few hours after the construction of the arch the centering should be slightly lowered by removing the wedges. This allows for a slight settlement of the arch before the mortar has dried. The whole centering should normally be removed 24 hours after completion.

28. (7) *Flat arches, and relieving arches, and lintels over door and window openings.*—Flat arches are made over door and window openings with bricks or stone, the vertical joints radiating to a centre, thus containing a segmental arch of radius generally equal to the opening. They should have a slight rise, which generally = span ÷ 70, or say **1 inch for a span of 6 ft.** They are generally $1\frac{1}{2}$ bricks thick and the bricks should be carefully cut or moulded. A flat arch cannot bear much weight of wall above it and must have a relieving arch over it springing from the wall clear of the top of the flat arch. The centering on which this relieving arch is built must be removed and the space left unfilled until the building is completed above it and the arch has completed its settlement.

If wooden lintels are used instead of flat arches, they should normally have relieving arches over them, the springings of which must be clear of the end of the lintel, which should therefore be built into the wall as short a distance as possible so as to economise in arch masonry. If by any chance relieving arches are not made, the lintel should be very substantial to take the weight, and should be built into the wall a considerable distance.

29. (8) *Inverted arches.*—The soffit is uppermost. They are built under an opening between piers or abutments to distribute

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the weight of the whole superstructure if it is specially heavy. Seldom necessary in forest buildings. They are generally segmental, but an arc with an angle between the radii of less than 45° should not be used.

E. *Pointing*.

30. Outside walls, unless built of inferior bricks, should as a rule be pointed and not plastered.

If lime mortar is used, slightly hydraulic lime with sand only should be used if possible. Strongly hydraulic lime, owing to the difficulty of slaking and of grinding fine enough, will have nodules which will cause blisters and cracking, though this is not so dangerous as in plastering. If a fat lime with surkhi has to be used, the surkhi must be of well-burnt bricks, as if it is made from ‘ pila ’ bricks, it will not be durable. The mortar must be absolutely free from lumps.

For method of pointing see United Provinces Forest Pocket Book, pages 293 and 294.

6. FLOORS.

A. *General*.

31. Floors may be of wood or of some other material such as bricks or concrete. Wooden floors are generally only used in the hills, or in the upper stories of buildings of more than one storey, or in buildings in damp climates or situations when the floor is raised some way above ground on posts or special walling. Floors of other materials such as bricks, etc., are generally used in the plains and wherever there is a danger of wooden floors being destroyed by white ants, damp, or other destructive agency. For such materials on ground floors the preparation of the surface of the ground is very important. The earth must be watered and rammed in layers so that the final surface is absolutely unyielding and level; or if, as in verandahs, the floor is to be on a slope, the earth surface must be parallel to it.

B. *Bricks*.

32. First put a layer of pure dry sand 3 inches deep as a protection against damp and white ants. This must be pure sand and not sandy earth, in which white ants flourish. Then a 3-inch layer of lime concrete should be well rammed. Lastly put one or more layers of bricks. The bricks must be 1st class, well-shaped and well-burnt, and of one quality as to hardness to prevent uneven wearing. The surfaces to be placed in contact with each other must be rubbed smooth so as to fit close. Mortar should be of lime or cement, and joints not more than $\frac{1}{16}$ inch. The number and arrangement of the brick layers depends on the wear to which the floor is to be subjected. One layer of flat bricks may be enough, especially if economy is necessary, but bricks on edge are better, and to resist hard wear and heavy weights one layer of flat bricks covered by one layer of bricks on edge may be used. If lime mortar is used, cement pointing is often done. The bricks should not be covered completely with a thin layer of plaster or concrete, as is sometimes done. This is generally done as an excuse to cover bad material. The bricks are generally laid in parallel rows, breaking joint.

C. *Tiles.*

33. For better class floors glazed paving tiles usually varying from 9 to 18 inches square and 2 to $2\frac{1}{2}$ inches thick may be used. The edges are trimmed square to fit tight, but the surface must not be rubbed, or the glazing will be removed. They should be laid with lime mortar on the same foundations as bricks, *viz.*, 3 inches sand and 3 inches concrete, and pointed with cement.

D. *Stone.*

34. If suitable stone is available it is better than bricks or tiles, as it is more durable. Stone flags may be of any convenient size, but generally at least 9 inches square and never less than $1\frac{1}{4}$ inch thick, and they should be carefully dressed square on all surfaces. They should be laid with lime mortar on the same foundations as above and pointed with cement.

The above 3 types of flooring must be kept wet for 7 days after laying, or for 10 days if cement pointed.

E. *Terraced.*

35. Lime concrete. This is better than brick flooring for dwelling houses, but not so good as good quality stone or tiles. It is important to use good mortar and to consolidate the concrete properly. Lay on a 3-inch layer of pure sand. One course of flat bricks over the sand may be added if extra strength is required.

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The lime concrete should be 3 to 6 inches thick according to the strength of floor required. Proportions 1 mortar, 2 aggregate. Gauge of aggregate generally $\frac{3}{4}$ to 1 inch. Consistency of concrete medium wet. For a 3-inch floor lay the concrete 4 inches thick and ram it very thoroughly till the mortar has partially set. During ramming sprinkle on it water mixed with 'gur' and 'bel' fruit ($3\frac{1}{2}$ seers *gur* and 2 seers *bel* to 25 gallons of water). This improves the strength and setting qualities of the mortar. When consolidation is complete sprinkle with clean water and smooth with trowels the fine mortar which has come to the surface during ramming. Then rub the surface with a piece of smooth stone or vitrified brick, and carefully wash off any surplus fine lime paste that comes to the top. The surface will eventually be rubbed to a fine polish. As polishing advances more *gur* and *bel* water should be sprinkled every now and then. After polishing cover with 2 inches of sand and keep it wet for 14 days.

N.B.—A separate layer of plaster should never be laid on top of the concrete, as this will always break up and wear into holes. The whole of the floor from the surface to the bottom of the concrete should be one homogeneous mass.

36. If funds are limited a cheaper floor can be made satisfactorily provided it is to be subjected only to light wear. 4 inches of broken aggregate without mortar should be watered and very thoroughly rammed till it will yield no more, and then a coat of good lime mortar well rammed in over the top. Smoothing and finishing to be done as detailed above.

N.B.—Terraced floors should not be repaired with plaster, but the damaged portions should be cut out $1\frac{1}{2}$ inches deep, and fresh concrete of not more than $\frac{3}{4}$ inch gauge laid and rammed in the holes.

F. *Cement concrete.*

37. An expensive floor, and only used in special cases. It consists of $\frac{3}{4}$ to 2 inches of cement concrete (1 : 2 : 4) of wet consistency with aggregate of $\frac{1}{2}$ inch or even smaller and laid over 3 inches lime concrete. Thorough ramming of earth filling under the concrete is specially important. For important work a filling of rammed broken brick or stone may be used. The cement concrete should be laid before the lime concrete has completely set, and it should be laid in sections—squares or strips of 4 to 8 ft. width—to prevent cracking due to contraction before setting. These sections are defined by flat bars of steel or wood of the same depth as the cement concrete and whitewashed to prevent

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their adhering to the concrete. Adjoining sections should be completed on different days. The cement concrete should be laid as soon as it is mixed. Only very light ramming is necessary. When the mortar comes to the surface smooth it over and polish with a trowel. The whole process should be finished within 15 minutes of mixing. The floor should be kept wet for 14 days and should not if possible be used for a month.

G. *Earth.*

38. This is the cheapest form of floor, and is only used when funds do not permit of a better type. The earth must be loam or clay and not sandy. It should be consolidated very thoroughly in 6-inch layers using as little water as possible.

A slightly better type of floor, which is less liable to become damp, can be made by ramming in 3 inches of broken brick or stone and covering it with bajri or fine gravel using plenty of water during ramming.

H. *Devonshire Barn.*

39. This consists of 3 to 6 inches of earth mixed with lime and well rammed. It succeeds only with certain soils, and preliminary experiments are necessary. Mix 5 lbs. of lime per c.ft. of finely powdered earth and add water to make a thick paste. Ram it in position and keep moist till the lime has set.

J. *Wooden Floors.*

40. On ground-floors the planks rest on joists which are supported on the flue walls or on pillars. Joists need not be closer than 2 to 3 ft.

In upper stories or in single-storey buildings supported on posts the construction of the floor depends on the span.

41. (1) *Single-joisted floor* has the planking resting on joists which span the whole width of the room unsupported. This can only be done for spans up to 16 ft., and if the span is more than 8 ft. the joists must be strutted to prevent them sagging or twisting. For 8 to 12 ft. spans 1 row of struts is necessary, and for 12 to 16 ft. spans 2 rows. The simplest form of struts is to insert a piece of board nearly of the depth of the joists between every two joists so as to form a continuous line across. The struts should fit tightly and be nailed to keep them in position. But a better form consists of short cross struts $3 \times 1\frac{1}{2}$ inches in between

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joists, and nailed near the top and bottom edges of joists, and to each other where they cross.

Joists should be 12 inches apart, and their dimensions are usually for 8 ft. span 6 × 1½ inches, for 12 ft. span 8 × 3 inches, and for 16 ft. span 10 × 3½ inches.

42. (2) *Double-joisted floor* must be used for spans of over 16 ft. The joists are supported by cross beams or girders at not more than 8 ft. intervals. In this case the joists can be 15 inches apart and need not be more than 5 × 2½ inches. Girders for 10 ft. span may be 8 × 5 inches, and for every additional 2 ft. of span their dimension should be increased by 1 inch depth and ½ inch width.

It is probably better to use a double-joisted floor for any spans over 8 ft. For instance with a span of 12 ft. much less timber is required if the floor is double-joisted than if it is single-joisted, and no elaborate struts have to be made. Another advantage of double-joisted floors, if a ceiling is fixed, is that sound does not pass through so easily. On the other hand a double-joisted floor with a ceiling means a thicker floor and an increase in height of walls to get the same height of room below.

43. (3) *Planks.*—The narrower the planking the less the opening of the joints through shrinkage. The width should be 4 to 6 inches, thickness 1 to 1½ inches, and length 6 to 12 ft. It is essential to use well-seasoned wood to minimise shrinkage and warping. Planks should be laid with their ends on joists and breaking joint. When they are laid they should be cramped tightly together with a carpenter's cramp before being nailed to the joists, and the cramp should be kept fixed until the nailing is finished. If a cramp is not available, the following method may be employed. Fit 6 planks as close as possible without nailing; raise the 6th and nail down the 7th a little inside the mark of the outer edge of the 6th; the 3rd and 4th are then raised with adjoining edges resting against each other, the 5th and 6th being placed flat against the 7th; when the 3rd and 4th are forced down into position, they tighten up all the others, and they are then all nailed down. The simplest joint is the plain butted joint, but if the planks shrink gaps are left right through; thus more elaborate joints, such as tongued and grooved, are better.

44. (4) *Fireplaces.*—These need special construction in an upper storey, as the normal arrangement of joists or beams built

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into the wall cannot be followed close to a fireplace. If the joists are running parallel to the wall in which a fireplace is constructed, 2 short timbers called trimmers are placed one on each side of the fireplace with one end resting in the wall and the other jointed into the 3rd joist from the wall. Into the outer sides of these trimmers the ends of the 1st 2 joists are jointed. The trimming joist into which the trimmers are jointed is thicker than the others. The hearthstone rests on a brick arch turned between the wall and the trimming joist. Two iron rods pass through the trimming joist and the bottom of the arch, and are embedded in the wall, their ends either being screwed into a block of wood built into the centre of the wall, or turned down at right angles into the wall. These rods help to resist the thrust of the arch.

If the joists are at right angles to the wall in which the fireplace is constructed, a similar arrangement is made, but with slightly different details.

45. A simpler way of constructing the fireplace, if slabs of slate are available (which is often the case in the hills), is to build the floor in the ordinary way and construct the hearthstone over it. A large slab of slate is placed over the joists in front of the fireplace, and another slab placed over this with a layer of earth in between. This forms the hearthstone, the layer of earth keeping the heat of the fire from damaging the timber. The joists under the slates must be made thicker to support the extra weight. If joists have to be built into the wall close to the fireplace, they should similarly be protected with a layer of earth in between slabs of slate or stone. This method is not quite so safe as that of using trimmers, etc., but it is much easier.

46. (5) *Ceilings.*—If a ceiling is fitted under the floor, the ceiling planks are fitted in the same way as floor planks, and nailed to ceiling joists, which in the case of a single-joisted floor are fixed by notching to the floor joists and at right angles to them, and in the case of double-joisted floor to the girders and parallel with the floor joists.

7. PROTECTION AGAINST DAMP AND WHITE ANTS.

A. *Protection against damp rising from the ground.*

47. (1) A common method in damp climates is to raise the whole building 6 ft. or more above ground on posts, *e.g.*, in Bengal,

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Assam and Burma. This is not possible for heavy masonry buildings. For these a high masonry plinth with ventilation through under the floor can be made. For plinths up to about 3 ft. high flues may be made running across under the ground-floor by building masonry walls on 3-inch concrete footings at short intervals across from one main wall to the other. The bricks must be the hardest available and the masonry should be plastered. Iron gratings fixed in the plinth masonry at both ends of each flue act as ventilators and keep vermin out. Instead of continuous flues masonry pillars may be used. These walls or pillars are built up to floor level at the necessary intervals for the support of the floor joists. This type is good for wooden floors, and all wooden floors should have underneath ventilation on this or similar principles.

The ground-floor may also be built over a series of arched flues, which may be up to 6 ft. or more high and several feet wide. These may be left open at both ends, or walled up with iron gratings for ventilation. In this case the floor may be terraced, or of any other heavy type.

48. (2) Damp proof courses—

(*a*) Through walls at plinth level. They should be not less than ½ inch thick and closely jointed to the floor. It is especially important to construct them if the superstructure is in mud mortar. They can be made of slate or other impermeable stone in cement mortar, of fine cement concrete, of cement plaster (proportions 1: 2), or of asphalt (which is however rather apt to become too soft from heat in the plains).

(*b*) Over the entire area of the building at plinth level. This is a better way, and any of the above 4 methods may be used. The course should be continuous under floors and through walls.

B. *Protection against white ants.*

49. (1) White ants' nests should be destroyed—see under preparation of site.

(2) White ant-proof courses—

(*a*) A layer of sand 3 inches deep under floors such as brick or terraced.

(*b*) An asphalt course throughout the area of the building at plinth level as described above will probably be useful.

(*c*) Coaltar. Any floor, such as brick or terraced, may have coaltar rammed into the lowest layer of aggregate. This may be done as follows:—3 inches of broken brick or stone should be well watered and rammed and covered by pure sand. Onto this 2 gallons of coaltar per 100 square feet should be poured hot, and again covered with fine sand. This should be rammed well, sprinkling more sand when necessary till the whole surface is firm and hard. The final layer of bricks or lime concrete can be laid over this.

(*d*) Yellow arsenic (*hartal*) is effective if mixed with the concrete of floors, and in the mortar of a brick floor and of the masonry in plinth and up to a height of 4 ft. in the superstructure. As the dust from materials so treated is poisonous, arsenic should not be mixed with the surface layer of concrete or with the plaster or pointing in dwelling houses. If the building is not a dwelling house and is not much frequented by people this precaution is not necessary. Proportions of arsenic as follows:—

4 lbs. per 100 c.ft. concrete.

$\frac{1}{2}$ lb. per 100 c.ft. masonry.

$\frac{1}{2}$ lb. per 100 sq.ft. plaster.

A similar material is copper nitrate (*nila tutia*) mixing 1 lb. in 4 gallons of water to be mixed with the mortar in concrete or masonry.

An extract made by crushing the leaves of *Adhatoda vasica* in water is also said to be useful when used in the same way.

8. Roofs.

A. *Summary of the different types.*

50. (1) *Flat Roofs*—

(*a*) Terraced. This is very like a terraced floor. It is laid on horizontal joists resting on wood or iron beams.

(*b*) Arched. The roof covering is similar to that of the above, but it is laid on brick arches:—One arch for small spans, but generally a series of small arches, called jack arches, between iron girders.

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(c) Mud. This is made on the same principles as a terraced roof, but using mud instead of lime concrete in cases where cheapness is essential and rainfall is light.

51. (2) *Sloping or Pent Roofs.*—The roof coverings are of many sorts depending partly on what is available locally, and partly on the funds available and the type of roofing considered necessary. The roof covering is supported on a timber framework called a truss, the form of which depends on the weight of the roof covering and the span of the roof. Steel girder trusses are commonly used now-a-days, especially for roofs of larger spans; but as forest buildings generally have a small span, and as timber is easily and cheaply obtainable in the forests, timber trusses are generally used, and only timber trusses will be considered.

B. *The comparative advantages of different types of Roof covering.*

52. (1) *Flat roofs.*—These are generally only used in the plains. They are heavy and need thicker walls and foundations than pent roofs, and except in the case of mud roofs are expensive. If well made they are very durable, and they are cool and are also fireproof. If funds permit and if the foundations are suitable for heavy buildings, they are probably better than other types in the plains. Jack arch roofs are preferable, as they are more durable, and less likely to settle and cause cracks in the concrete if well made; but they are more difficult to make and more expensive, especially when suitable timber for ordinary terraced roofs is easily obtainable. The latter are therefore more often made in the forests.

53. (2) *Sloping roofs.*—These are generally cheaper and lighter than flat roofs.

(a) *Thatch.*—Very cheap, as grass is nearly always available, cool, light, and easy to construct; but not durable, need frequent repairs and renewal, difficult to keep waterproof, highly combustible, and harbour insects, snakes, and vermin. They are not much used now-a-days, except for temporary buildings in the forest, for which they are suitable owing to their cheapness.

(b) *Tiles.*—Much used for forest buildings in many parts of the plains, and form a good covering where tiles are available. Fairly cool and durable and fireproof, though fairly frequent repairs are necessary unless the tiles are of very good quality. Mangalore

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or Allahabad or similar tiles are the best, but are not often easily available, and country tiles are most often used.

(c) *Slates.*—Much used in the hills where available. Suitable for forest buildings, the advantages being much the same as for tiles.

(d) *Galvanized Corrugated Iron.*—Lighter and more durable than tiles or slates, fairly cheap, easy to construct, and fireproof. It is very often used both in plains and hills. Disadvantages are that the buildings are apt to be very hot, and the noise of rain on the roof is objectionable. If funds permit, a wooden ceiling or plank lining under the iron, or shingles or tiles laid over the iron, will make the building cooler. The latter make a very rainproof and cool roof, and looks much nicer.

(e) *Shingles or planks.*—A very useful type of roof in the hills, when suitable wood is available, and the cost of transport of other materials is too great. Cheap and light, but not fireproof and only fairly durable, and very liable to leak unless very carefully made and laid. Seasoning of the wood is very important.

C. *Roof Slopes.*

54. It is very important to give a roof the correct slope. This varies chiefly according to the type of roof covering. In the hills the amount of snow likely to fall is also an important factor.

The slope or pitch of a roof is measured either by the angle it makes with the horizontal, or by the difference in height in a certain horizontal length; *e.g.*, 1 in 2, or a rise of 1 ft. in a horizontal distance of 2 ft.

A slope of 1 in 1 = 45°
,, ,, 1 in 1½ = 33° 41′
,, ,, 1 in 2 = 26° 34′
,, ,, 1 in 2½ = 21° 48′
,, ,, 1 in 3 = 18° 25′
,, ,, 1 in 4 = 14° 2′
,, ,, 1 in 20 = 2° 54′

55. The following are the usual slopes given to roofs according to the roof covering :—

Allahabad and country tiles, 1 in 2.

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They will slip if laid steeper, and be inclined to leak if laid flatter.

Mangalore tiles if screwed down, 1 in 1.

Mangalore tiles if not screwed down, 1 in 2.

Shingles, 1 in $1\frac{1}{2}$ to 1 in 2.

Thatch never less than, 1 in $1\frac{1}{2}$.

If laid flatter it will absorb too much water and will leak.

Slates from 1 in $1\frac{1}{2}$ for small slates to 1 in $2\frac{1}{2}$ for large slates.

Corrugated Iron—Minimum slope 1 in 4, but may be laid as steep as 1 in 1.

Naini Tal pattern and similar kinds of roof, 1 in 2.

Terraced roof, not less than 1 in 20.

56. In the hills if snowfall is heavy the roof should be as steep as possible. Snow will not usually lie on a slope of 1 in 1 or steeper. Therefore the roof should be as near this as possible. Corrugated iron may be made 1 in 1, but slates and tiles must not be steeper than as indicated above or they may slip. Shingles might be a little steeper, say, up to 1 in $1\frac{1}{4}$. In an area of heavy snowfall, if the roof cannot be made as steep as 1 in 1, it is important, therefore, to allow for the weight of snow likely to lie on the roof when calculating the size of timber required for the roof truss.

D. *Roof Construction—The Arrangement of the Timber.*

57. In the following notes distance between beams and other timbers is always from the centre to centre, and the span of a roof, etc., is from the centre of one point of support to that of the other, *i.e.*, in the case of most roof trusses from the centre of one wall plate to the centre of the other. If the 'clear span' is mentioned, this means from wall to wall.

(1) *Flat Roofs.*

58. (a) *Terraced.*—Wooden beams are laid across the width of the room, generally being from 4 to 8 ft. apart. The exact spacing depends on the length of the room, and on the size of timber available. The dimensions depend on the weight to be carried, *e.g.*, for a room measuring 16 × 12 ft.:—beams will be placed across the 12 ft. width. One beam across the centre of the room will be sufficient if timber of large enough size is available. If timber of the necessary dimensions, *viz.*, 13×5 inches, is not available, it will be necessary to have 2 beams at 5 ft. 4 inches interval. Each beam will then have less weight to carry and can be made smaller, *viz.*, $10 \times 4\frac{1}{2}$ inches. Joists are laid over the beams at right angles to them. Their spacing depends on the measurement of the bricks or tiles to be laid over them, which are generally from 9 to 12 inches long. Their size depends on the weight to be carried, but the breadth is not generally less than $2\frac{1}{2}$ or 3 inches, so as to give sufficient bearing to each brick or tile. For small spans up to 8 ft. (*e.g.*, a verandah) joists alone may be used.

(b) *Jack-arched.*—No timber is used. The brick arches rest on rolled steel beams 4 to 6 ft. apart laid across the width of the room.

(2) *Sloping Roofs.*

59. The arrangement of the timber depends chiefly on the span of the roof, and partly on the weight to be supported.

(a) *Lean-to.*—For spans up to 10 ft. This is the simplest type consisting of a single sloping surface, and is used for small sheds or verandahs against a wall or main building. The rafters are notched and spiked, or simply spiked directly to the wall plates or post plates.

(b) *Coupled Rafter.*—For spans up to 12 ft. The rafters are used in couples, one from each wall. Their upper ends are spiked to a ridge pole, which runs lengthways along the top of the roof, and their lower ends are fixed in the same way as in the case of a lean-to roof. The top ends of the rafters may also be half-lapped, *i.e.*, joined by halving over the top of the ridge pole. This is generally considered a better way.

(c) *Collar.*—For spans of 12 to 14 ft. To prevent the outward thrust of the rafters against the walls, which would be too great in a coupled rafter roof of over 12 ft. span, they must be tied together. In this case a collar is used, placed horizontally half way up the rafters, the joint sometimes being dovetail halving, though it is better not to cut the rafter, as this weakens it unduly at the point of greatest stress, and in this case the collar alone is halved.

(d) *Couple-close.*—For spans of 14 to 18 ft. The tie joins the feet of the rafters, the joint being halving as in the case of the collar, but in this case the rafter may also be cut. If the span is more than 16 ft., or in any case if a ceiling is attached, an iron rod or king bolt is used between the ridge pole and the centre of the tie beam to prevent the latter sagging.

60. The above 4 types of roof are single-raftered, the roof covering being placed directly on the rafters, with the addition of horizontal battens or planks when necessary. The usual distance between trusses is from 2 ft. 6 inches to 4 ft. Trusses should be equidistant from each other, and the actual spacing used depends chiefly on the length of the room to be roofed, *e.g.*, for a room 12 ft. long there may be either 3 trusses 3 ft. apart or 2 trusses 4 ft. apart. It is usual to fix what appears to be the most suitable spacing in this way, remembering that if a chimney has to be built up in the long wall of the room, the trusses must come a certain distance on each side of it. The necessary dimensions of the rafters will then depend on the weight of the roof to be supported, the species of timber to be used, and the unsupported length of the rafters. The way to calculate this will be explained later under "Strength of Timber and Calculation of Dimensions". The unsupported length of a rafter in the cases under consideration is the distance from the ridge pole to the wall plate. This can be measured from the plan of the truss. In the case of a roof of a slope of 1 in 2 it roughly equals $\frac{\text{span of roof}}{2}\times\frac{10}{9}$. If it is desired to use rafters of certain fixed dimensions, then the maximum spacing permissible according to the weight of the roof, etc., must be calculated, and this spacing will then be used unless it has to be reduced to suit the length of the room or to avoid a chimney.

61. As a guide to the dimensions necessary, the following figures may be useful:—

For *sal* or teak, with a load of 25 lbs. per square ft., slope 1 in 2, and spacing the trusses 4 ft. apart, use the following sizes of timber:—

Span 10 ft., Rafters 3 × 2 inches, Tie or collar (where used) 3 × 1 inches.

Span 12 ft., Rafters 4 × 2 inches, Tie or collar (where used) 3 × 1 inches.

Span 14 ft., Rafters 4½ × 2 inches, Tie or collar (where used) 3½ × 1 inches.

Span 16 ft., Rafters 5 × 2 inches, Tie or collar (where used) 4 × 1 inches.

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If the load is 40 lbs. per square ft. the trusses should be 2 ft. 8 inches apart for the same sizes of timber. If deodar or *kail* (*Pinus excelsa*) is used the trusses should for the same sizes of timber be 2 ft. 8 inches apart for a 25-lb. load and 2 ft. apart for a 40-lb. load.

Ridge poles vary from 6 × 2 to 8 × 3 inches according to the unsupported length. They should normally be supported at intervals of not more than 15 ft. either by cross walls or posts.

Wall plates may be $4\frac{1}{2} \times 3$ inches laid flat.

The above dimensions are all that is necessary for trusses made of seasoned wood and by skilled carpenters. If, as often happens in the forest, timber is not properly seasoned, and carpenters not very skilled, it will be safer to increase the dimensions slightly, especially those of the tie or collar, which may be made $1\frac{1}{2}$ or 2 inches broad.

62. For spans of 18 ft. and above main trusses or principals are used, spaced generally 7 to 11 ft. apart, and connected by horizontal purlins and ridge pole, on which are laid the smaller or common rafters which support the roof covering.

(e) *King Post Truss.*—For spans of 18 to 30 ft. The truss is composed of principal rafters, tie beam, king post, and struts. The weight of the roof covering is first carried by direct transverse stress on the common rafters, and from them to the purlins and ridge pole, and they in turn bear on the joints of the truss. There is thus no direct transverse stress on the truss. There is also no outward thrust on the walls, which carry the whole weight vertically.

The carpentry joints have already been dealt with under carpentry.

63. For the spacing of trusses a general rule for loads of from 30 to 60 lbs. per square ft. is that the minimum spacing should equal $\frac{\text{Span} + 4\frac{1}{2}\text{ ft.}}{3}$. For spans of 24 ft. the spacing is, *e.g.*, $9\frac{1}{2}$ ft. If a ceiling and special ceiling joists are fixed, $\frac{3}{4}$ of the above should be used. A small increase in spacing to suit the length of the room does not matter.

As the calculation of the dimensions necessary for the timber in the truss is rather elaborate, the following table of sizes is given for a roof slope of 1 in 2, load on roof 40 lbs. per square ft., ceiling

7 lbs. per square ft., and trusses 10 ft. apart. Dimensions in inches:—

Member.	Clear span in feet.			
	16	20	24	
Principal Rafter	3×4	3×4	4×4	4×4
Strut	3×3	3×3	4×4	4×4
King Post	3×3	3×3	4×4	4×4
Tie beam with ceiling . . .	3×4	3×5	4×5	4×6
Tie beam without ceiling . . .	3×3	3×4	4×4	4×5

Different kinds of timber, and variations in span and spacing of trusses up to ± 25 per cent. make no difference. Variations in the load of the roof also do not make much difference.

64. The common rafters must come over each main truss, and there will be one or more equally spaced in between. The size of the purlins and common rafters can be worked out as for timber under transverse strain. As an example of the dimensions used and the method of procedure for calculating the spacing the following is given:—

For a room 50×24 ft. with 18 inch thick walls; roof covering double Allahabad tiling; slope 1 in 2; load 60 lbs. per square ft.; timber *sal;* spans for trusses 25½ ft. (24 ft. *plus* ¾ ft. at each side to centre of wall plate); length of room 51½ ft. (centre to centre of walls); theoretical minimum spacing of main trusses 7½ ft. (¾ of 10 ft. owing to ceiling); to fit into a length of 51½ ft. there must be 6 trusses spaced 7·4 ft. apart; the common rafters can be spaced either 3·7 ft. or 2·47 ft. As the roof is a heavy one the closer spacing will be advisable; battens 1 ft. apart. Dimensions as follows:—

Battens, 1½×1 inches.
Common rafters, 4½×2 inches.
Purlins, 6×3 inches.
Ridge Pole, 7×2½ inches.

Timber in the main truss as given for 24 ft. clear span.

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65. (f) *Queen Post Truss.*—For spans of 30 to 45 ft. This truss has two vertical posts called 'queens'. It is rarely used now-a-days, as most trusses of over 30 ft. span are made of steel.

66. (g) *Gable and Hipped Roofs.*—When designing the roof of a building it is also necessary to decide on the general shape of the roof, *i.e.*, whether it is to be a gable or a hipped roof.

In a gable roof the roof is finished off vertically at the end, the end walls being continued up to the ridge pole, thus filling up the space between the 2 roof slopes.

In a hipped roof the ends of the roof are sloped down, so that the end walls are the same height as the side walls. Both ends are hipped, so that the roof consists of 4 sloping surfaces. If the building is square it is usual to make all 4 slopes meet at a point, and they will all be triangles. If the building is not square, only the 2 end slopes will be triangles, and the other 2 will meet in a ridge. The length of the ridge will normally be fixed by subtracting the breadth of the building from its length. It is, however, possible to construct a hipped roof without adhering to the above principles, but the slope of the 2 end triangles will not be the same as that of the side portions. This does not matter in, *e.g.*, a corrugated iron roof, but a tiled roof must have all the slopes the same.

The main rafters joining the ridge pole to the corners of the building are called hip rafters. The small rafters which descend from the hip rafters in pairs at right angles are called jack rafters. The ends of the ridge pole may rest on walls, or they may be supported by trusses. The former is easier, but it may often be difficult to arrange the rooms of the building so that the walls come at the correct place.

E. *Roof Coverings.*

67. (1) *Flat Roofs.*—(a) *Mud.*—Tiles or bricks or slabs of stone are laid in lime mortar over the joists. The upper and lower surfaces should be pointed. Over this clay (a good brick earth) is rammed to 6 inches thickness till quite stiff and hard. On the top is laid a coat of mud plaster (stiff clay mixed with chopped straw) 1 inch thick. When this is dry it should be leeped with a mixture of clay and cowdung in equal quantities. Slope should be 1 in 8. This is a cheap roof, but requires much attention. Leeping must be renewed annually and plastering every few years. It should

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only be used where the rainfall is light, *e.g.*, parts of the Punjab plains.

An even cheaper form for temporary buildings, where there is no danger from white ants, is to substitute reeds or twigs (bound tightly in small bundles and closely packed) for the bricks or tiles. In some places planks are used instead of bricks or tiles, but this is not recommended.

68. (b) *Ordinary Terrace.*—Bricks or tiles or stone flags are laid in lime mortar over the joists. The best size for tiles is 12 × 12 inches and from 1 to 2 inches thick. If the tiles are only 1 inch thick 2 layers should be laid breaking joint. Over this is laid lime concrete (lime mortar 1 to $\frac{3}{4}$ inch aggregate $2\frac{1}{2}$) to be 3 to 6 inches thick when rammed. The laying of the concrete is the same as for terraced floors. It is even more important not to put a separate layer of plaster on the surface, as it will produce a surface skin which swells and cracks during the rains and causes leaks. When the roof is finished a layer of grass or old mats should be placed over it and covered with an inch of sand, and kept saturated with water for at least 14 days. This covering should be left on till just before the rains. It is usual to carry the wall up into a parapet, and it is important in this case to make sufficient allowance for drainage of water through the parapet. If no parapet is made, the terracing should be carried for its full thickness over part of the outer wall. The roof may be surfaced with cement by sprinkling 16 lbs. cement per 100 square ft. while polishing is being carried out.

The necessary slope may be given to the roof in the beams or in the thickness of the concrete, the latter being the better method. When cracks appear in the concrete, repairs may be done in various ways. If the cracks are large, they should be raked out and uneven and broken edges cut away, so that the crack is at least $\frac{1}{4}$ inch broad, and as deep as it can be made with a trowel. Water should be poured into the cavities and left till it has soaked in. Then cement mortar (either pure cement or cement 1 sand 1) should be forced into the cracks and smoothed over flush with the roof surface.

If the cracks are very fine a coat of tar is generally sufficient; or better still 2 coats of tar with a strip of ordinary 'dasuti' in between. If there are a number of fine hair cracks all over the surface, a coat of cement cream may be applied. Various other mixtures can be used for pouring into cracks to make them watertight; *e.g.*, linseed oil (2 parts), resin (2), and pumice stone (1). Boil the oil, then mix resin pounded fine, and lastly pumice stone also pounded fine. The cracks should not be dug out, but the hot mixture should be poured straight in and the surface smoothed over.

In an old roof the beams sometimes sag, so that the centre of the roof is not higher than the edges. If funds do not permit of a complete new roof, leaking may be prevented by cutting drainage channels in the terrace at frequent intervals from the centre to the edges. They should, of course, get gradually deeper as they proceed from the centre to the edge of the roof. They should be lined with cement plaster.

69. (c) *Reinforced Brickwork.*—A comparatively new method of constructing a terraced roof is to lay the lime concrete over reinforced brickwork, which takes the place of the timber beams and joists and the ordinary bricks or tiles. This is cheaper to construct where timber is expensive, and if well made will probably be more durable. The principle of construction of reinforced brickwork is somewhat similar to that of reinforced concrete, and a centering is necessary. For a span of 8 ft. 1 layer of bricks on edge is sufficient, and for spans of 10 ft. 2 layers of bricks laid flat. It is probably inadvisable to use this form of roof for spans of much more than 12 ft. Iron rods $\frac{3}{8}$ inch diameter bent into a hook at the ends are placed along the mortar joints parallel with the length of the bricks. The joints containing the rods are $1\frac{1}{8}$ inch thick, and the rods should be a clear $\frac{1}{2}$ inch above the bottom of the bricks. The cross joints between the ends of bricks are $\frac{1}{2}$ inch thick. Cement mortar is used containing ‘ bajri ’ up to $\frac{3}{16}$ inch gauge. Each row of bricks should break joint with the next row. The brick work should be given a camber of $\frac{1}{2}$ inch per foot of span. The centering should be left for a week after construction, and the terracing should not be done for at least 2 weeks after removal of the centering.

70. (d) *Jack Arch.*—Arches of brick in lime or cement mortar are carried on rolled steel girders. Girders are spaced 4 to 6 ft. The rise of the arches is $\frac{1}{8}$ the span. The arches are $\frac{1}{2}$ brick ($4\frac{1}{2}$ inches) thick and spring either from the top or the bottom flange of the girder. To take the thrust of the outer end arches iron tie rods of not less than $\frac{1}{2}$ inch diameter are fixed from the end girder through to the outside of the wall. They should be 3 inches above the bottom of the girder, and spaced not more than 20 times the width of the girder, but generally closer. Centering is necessary. The top surface of the centering should be of as impermeable a clay as possible to prevent the mortar from running through the joints. When the arches are complete lower the centering slightly to allow the arches to settle, but then leave them till the concrete terracing on top has set. Jack arches, when built from the top flanges, may be covered with 2 inches of fine concrete following the waves of the arches, *i.e.*, the top of the roof will not be flat, but will consist of a series of curves.

N.B.—Old rails can be used as girders for spans up to 18 ft. They should be given a camber of 2 to 4 inches at the centre, and be spaced 4 ft. apart.

71. (2) *Sloping Roofs.*—(a) *Thatch.*—Bundles of long thatching grass are fixed on a bamboo framework, which rests on wooden battens laid 3 ft. apart on the roof rafters. The bamboo framework may be made with vertical rows of single whole bamboos 1½ inches diameter and 1 ft. apart, and split bamboos fastened at right angles 6 inches apart with good *munj* string. The thatch is from 3 to 12 inches thick, laid in 3-inch layers beginning from the eaves. A fresh layer is required every 3 or 4 years.

As new thatched roofs are very seldom made nowadays for permanent buildings, no further details will be given. Full details of one of the many ways of making a thatched roof will be found in the Appendix to Section VI of the Roorkee Treatise of Civil Engineering.

72. (b) *Tiles.*—*Country Tiles.*—There are various types of tiles and methods of laying. The commonest is semicircular pot tiles laid single or double on a bamboo framework fastened to the rafters. The size of the tiles varies. They are generally ¼ inch thick, 8 to 10 inches long, and 4 to 6 inches wide at one end tapering to 3 to 5 inches at the other. The concave under tiles have their broad ends uppermost, *i.e.*, towards the ridge, and the convex upper tiles the reverse. This prevents them slipping down over each other. They should overlap 3 to 4 inches, and like all overlapping roof coverings are laid from the eaves upwards. Ridges, eaves and hips are set in lime mortar. Special ridge tiles are laid along ridges and hips. Pot tiles can be laid over pan tiles in the same way. Pan tiles are usually more or less flat with the edges curved up. A better type of roofing is to have flat tiles underneath in lime mortar and abutting against each other, and then pot tiles or pot and pan tiles over them. The size of flat tiles varies from 12 inches

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square to 4 inches square. In the above types of roofing the bamboo framework is not recommended, as it only lasts a few years. Flat tiles should be laid on battens, the spacing of which depends on the size of the tiles. The tiles are either nailed to the battens or supported by projections on their under surface. Pot tiles, if used alone, should be laid on planking.

73. *Allahabad Tiles.*—These are much used in the United Provinces. They are laid single or double on battens 1 ft. apart. They are larger and heavier and of better quality than country tiles. Double tiling consists of 4 layers:—

1. Flat tiles with edges slightly turned up.
2. Semi-hexagonal tiles laid over the joints of the 1st layer.
3. Another layer of flat tiles.
4. Half round tiles laid over the joints of the 3rd layer.

Each tile overlaps the one below it by 3 inches, close fitting being ensured by specially moulded niches and lugs. The 3 lowest tiles in each line will be set in lime mortar as well as the special ridge and hip tiles. The ends of each row of semi-hexagonal and half-round tiles will be filled up with lime mortar, and in double tiling also the spaces between the 2 rows of flat tiles. Single tiling consists of the 1st and 4th layers as above.

Mangalore and Sialkot Tiles and other special patterns are used in certain parts of India, the general principles of laying being much the same as for Allahabad tiling.

74. (c) *Slates.*—These vary much in size and quality. They are laid on planking or battens. The usual spacing of the battens $= \frac{\text{length of slates less 2 inches}}{3}$, *i.e.*, for the average size of $20 \times 10 \times \frac{1}{4}$ inches at 6-inch intervals. The slates are fixed by nailing, generally 1 nail per slate in the middle of the slate and into the batten next below that on which the top of the slate is resting. Every course of slates should break joint with that above and below it. Over the ridge pole, which should project 3 inches above the slates, zinc or galvanized iron sheeting is laid, the sheets overlapping each other by 3 inches, and at least 6 inches over the top slate on each side of the ridge. These ridge sheets should be secured with straps of hoop iron bent over at 2-feet intervals and bolted through to the ridge pole.

For better class buildings artificial asbestos or bituminous slates are often used in the hills (*e.g.*, Eternit).

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75. (d) *Shingles.*—These should be split, if possible, as they are then more durable and absorb less moisture. But they are often sawn. They must be sound, and free from cracks and flaws and sapwood. The size varies, but a usual size is 15 × 5 inches, and ½-inch thick tapering to ¼-inch. Before laying they should be dipped in boiling earth oil, or in a mixture of oil and creosote. They must be thoroughly dry before dipping. After laying they should be brushed over with the same mixture every other year. They are laid on battens (2 × 1 inches laid flat), in much the same way as slates. For 15-inch shingles, the battens are 5 inches apart. The overlap is 10 inches. Each shingle is nailed with two 1¼-inch nails. Successive layers should break joint. They should not be laid too close, or they will rise when expanded by moisture. A double thickness is laid at the eaves and ridges. Zinc sheeting may be laid over ridges and hips as for slates, or special ridge boards may be used, and they should be nailed through to the rafter or ridge pole below.

76. (e) *Planks.*—These are less satisfactory than shingles, and more liable to leak. They are only used for unimportant buildings. They are generally laid with the planks horizontal, *i.e.*, parallel to the ridge, and overlapping half their width. They are nailed directly to the rafters, 2 nails at each place they cross the rafters. They may also be laid vertically, *i.e.*, at right angles to the ridge. In this case 2 layers breaking joint are necessary, and they are nailed to battens, or if the building is small, horizontal purlins without rafters may be enough. Caulking the joints between planks greatly lessens the danger of leakage. The joints should be filled with hemp or some other fibre, and hot pitch poured over it.

77. (f) *Corrugated galvanised iron.*—Corrugated iron is rolled sheet iron bent into a series of ridges and hollows called corrugations, which make it stronger and stiffer. The surface must be clean and bright and free from rust, and should not have any white powdery deposit on it. The size of sheets varies from 6 to 10 ft. in length and 2½ to 3 ft. in width. Gauge numbers, *e.g.*, 20, 22 and 24, show the thickness, the larger the gauge the less the thickness. 22 gauge is most often used. The following table gives the weight in lbs. per square ft. of sheets and fittings:—

Gauge	20	22	24
Without laps	1·85	1·55	1·29
With 6 inches end lap and 2 corrugations side lap.	2·33	1·95	1·62

The sheets are fixed to 3 × 2 inch battens, which are laid across the rafters. The battens must be firmly fixed to the rafters to prevent removal by wind, and must be placed one under each end of a sheet, and if the sheet is long, one under the middle as well. The battens at the ends should have 2 inches of sheet overlapping beyond them both above and below. The sheets should overlap each other 6 inches lengthways and 2 complete corrugations sideways. For 6-feet long sheets the spacing of the battens is $5\frac{1}{2}$ ft. For 10-feet sheets with battens under the centre as well the spacing is $4\frac{3}{4}$ ft. Sheets should be fastened to the battens by $2\frac{1}{2}$ or 3-inch galvanised iron screws, or with hook bolts (the latter are generally only used with iron battens)—a screw or bolt every 3rd corrugation, and at all corners and overlaps. Those at the ends of sheets should be in the middle of the overlap. Holes must be on the crest of corrugations, and just big enough to allow for expansion and contraction of the screw. Holes should be punched from underneath. Lead washers are placed under the head of every screw or bolt and bent to fit the curve of the corrugation, and should project $\frac{1}{2}$ inch beyond the edge of the hole in the sheet. Screws and bolts should be set in white lead paste. Instead of screws or bolts special limpet bolts and washers may be used. When the bolts are screwed tight the washers adapt themselves exactly to the curve of the corrugations, and white lead paste is not necessary. Wind ties of $1\frac{1}{2} \times \frac{1}{4}$ inch bar iron should be used along near the eaves and gables, being placed over the corrugations and bolted through to the battens and rafters by $\frac{1}{2}$-inch bolts at intervals of not less than 4 ft. It is even better to bolt them through to the masonry using 18-inch long bolts and 6-inch square iron plates embedded in the masonry. Hips and ridge should be covered with zinc or galvanized iron sheet caps, each length overlapping the next by at least 9 inches. These should be screwed down to the battens or rivetted to the corrugated iron sheets. Another method of fastening the sheets is to use screws or bolts only at corners where 4 sheets overlap, and to fasten the sheets together with galvanized iron rivets and washers placed at between 1 and 2 ft. intervals along the edges of sheets both at the sides and ends. The sheets are made up into sets on the ground for rivetting, 3 or 4 sheets in breadth and 3 in length. Skilled labour is necessary for this.

78. There are several more complicated and expensive methods of roofing with galvanized iron sheets—either plain or corrugated. One of the best known is the Naini Tal pattern roof. The chief advantage of this, and other similar methods, is the avoidance of exposed bolt or screw holes through which rain may leak. In the Naini Tal pattern roof planks are laid horizontally over the rafters, and battens are fixed at intervals downwards across the planking. The iron sheets are laid on the planking and have their edges turned up close to the battens. Covering strips of plain sheeting are bent to the exact shape to fit over the battens and the edges of the sheets. The ridge is covered on somewhat similar principles. All fastenings are under overlaps.

79. If tiles or shingles are laid over corrugated iron, the necessary battens for fixing them on are fixed to the iron sheets by small galvanized iron bolts or screws. Country tiles can be laid direct on the iron sheets, and a batten fixed at the eaves to prevent the tiles slipping.

F. *Verandah Roofs.*

80. Verandahs may be any width up to about 12 ft., but normally 7 to 10 ft. is enough according to the size of the building. Their roofs may be in continuation of the main roof, or at a lower level. The advantage of the latter is that clerestory windows may be made above the verandah roof, and this gives extra light and ventilation to the rooms.

There are various ways of fixing the verandah roof rafters to the main wall in the case of sloping roofs at a lower level. In every case care must be taken to prevent leaking at the point where the rafters and roof covering join the main wall.

G. *Flashings.*

81. These are sheets of lead, zinc, or galvanised iron placed to cover joints which would otherwise admit water and cause a roof to leak. They must be used where chimneys, skylights, etc., project through the roof. In the case of a chimney projecting below the ridge of a roof, on the upper side a sheet is placed under the roof covering and turned up about 6 inches against the chimney wall. Another piece of sheeting is fixed in the masonry above it and bent down over it. The overlap should be 3 to 4 inches, the upper edge, which is turned into the wall, is fixed by being tucked into the joints of the masonry, which are raked out to a depth of 2 inches. It is wedged in with plugs of wood, and the joint finally filled in with mortar. It is possible to use only one piece of sheeting, but 2 pieces are preferable, as the ends are then left free to expand and contract. At the sides and lower edge of the chimney flashings must be fixed above the roof covering.

9. Ventilation.

82. Ventilation to provide fresh air in a building and get rid of bad or heated air is very important, and is often apt to be neglected in forest buildings. Ordinary doors and windows are one means of ventilation, but as heated air always rises, they are not sufficient, and some outlet must be provided in or near the roof or ceiling. Clerestory or other small windows close to the top of the walls is one useful method. But it is not always possible to make these, especially if the roof is hipped. In this case if a plank ceiling is fixed, small holes may be left in the ceiling and covered with perforated tin plates or wire gauze. In other cases a passage may be provided along the tops of walls or at gable ends, so that hot air may escape between the wall and the roof. Another method, which is possible in the case of, *e.g.*, an ordinary corrugated iron roof is to make a ridge ventilator. These are made by prolonging the rafters over the ridge pole for about 2 to 2½ ft. Short rafters are then attached to the ends of the main rafters, being supported where they meet by vertical suspending pieces rising from the ridge pole. Corrugated iron covering is then fixed on battens over the short rafters. The ventilation spaces between the short rafters and the main roof should be covered with wire gauze or fine wire netting to keep out birds and vermin. A disadvantage of this method of ventilation is that it lets in dust and air to an excessive extent, as the ventilation space cannot be closed if required.

10. Ceilings.

83. For flat roofs ceilings are not generally made. For pent roofs a ceiling should be fixed if funds permit. For keeping out heat, *e.g.*, under a corrugated iron roof, a wooden ceiling of planks is the best. Otherwise, if it is only required to improve the appearance and to keep dirt and vermin from falling into the rooms, other lighter and cheaper ceilings may be used. The following are some of the commoner types of ceilings:—

A. *Plank Ceiling.*

84. Planks are generally ½ to 1 inch thick, and not more than 6 inches broad. They must be well seasoned. Joints should be

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tongued and grooved, or else if they are only butted they should be covered with beading, *i.e.*, wooden fillets or strips at least 2 inches wide; or the planks may be lapped. Tightly fitting tongued and grooved joints are the best owing to the danger of dust and dirt working through in the other kinds. The planks are nailed directly to the roof timbers, or to special ceiling joists spaced at not more than 3 ft. intervals.

B. *Ceiling cloths.*

85. These are cheap, but unsatisfactory. The cloth is stretched on light timber frames, preferably not exceeding 5 × 5 ft. The frames are screwed to the roof trusses or ceiling joists, and the joints are covered with wooden fillets. Special whitewash made from Paris whiting or powdered chalk should be used, as ordinary lime whitewash rots the cloth.

C. *Lime plaster on wire netting.*

86. This is a good and cheap ceiling. Wire netting of ungalvanised wire of mesh not greater than $\frac{3}{4}$ inch is stretched across the rafters or ceiling joists spaced not more than 18 inches apart. $1\frac{1}{2}$ inch nails are used at 6 inch intervals with 1 inch driven into the timber and $\frac{1}{2}$ inch bent over the wire and hammered down. The wire must be stretched tight. The edges of separate lengths should be tied together with soft iron wire. The netting is first brushed over with a thin mixture of lime mortar mixed with fine chopped jute or other similar fibre. Then 2 coats of ordinary lime mortar (1 lime 2 sand, or 1 lime 1 sand 1 surkhi) with the addition of finely chopped jute (25 lbs. to 100 c.ft. mortar) should be applied with a trowel.

The ceiling should be kept wet for several days.

D. *Mud plaster on wire netting.*

87. This should only be used in dry climates where there are no white-ants. Wire netting of 1 inch mesh may be used.

Two coats of ordinary mud plaster are applied, and when dry the underside is leeped.

88. E. *Galvanised iron sheets.*—With joints covered with wooden fillets, or *special ceiling tiles* are sometimes used.

11. FIREPLACES AND CHIMNEYS.

89. There are 3 essential parts:—

Fireplaces.
Chimney flues through the walls to the roof.
Chimney stacks above the roof.

Every fireplace must have a separate flue.

A. *Fireplaces.*

90. The size of the opening is generally from 2 × 2 ft. to 3 × 3 ft. Depth from back to front for wood fires should be 18 inches. The back and sides must converge towards the flue opening (called the throat of the chimney), and this must be immediately above the centre of the fireplace, and a short way above the top of the fireplace opening. The back and sides should if possible be lined with fire bricks for a height of at least 12 inches, or be faced all the way up with fire clay (*see* U. P. Forest Pocket Book, page 302). A smoke lick, which is a shallow groove 4½ × 1½ inches running up the back of the fireplace to a point about 2 ft. above the top of the fireplace opening, is said to assist in the prevention of smoking. A hearthstone in front of the fireplace is essential if the floor is wooden. A low fender round the front of the fireplace is also useful.

B. *Flues.*

91. In ordinary dwelling houses the sectional area of the flue should normally be 144 square inches, *e.g.*, 12 × 12 inches, or 16 × 9 inches. Small fireplaces may have flues of a smaller sectional area, but the minimum for the main length of flue should be 81 square inches, *i.e.*, 9 × 9 inches.

As to the best shape opinions differ as follows:—

(1) The sectional area and the shape of the flue the same all the way up. (*See* U. P. Forest Pocket Book, page 303.)

(2) The throat smaller in area than the rest, *e.g.*, throat 9 × 4 inches and the rest 9 × 9 inches. (*See* Roorkee Treatise and Military Engineer Services Handbook.)

(3) The throat the same sectional area as the rest, but made long and narrow, *e.g.*, throat 13½ × 6 inches and the rest 9 × 9 inches.

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The advantage of No. (2) is said to be that the smoke is drawn up the flue better. Provided the main part of the flue is big enough for the size of fireplace, it probably does not matter which of the above three principles is followed.

Where the sectional area is not a square, the greatest width will always be parallel to the face of the wall.

Flues should be plastered with mortar made of clay and cowdung, or of lime (1) and cowdung (3). This is less likely than ordinary plaster to crack and peel off due to heat. Flues may be constructed round wooden frames made the correct size and about 3 ft. long. Any necessary curves should be gradual. The walls, up which the flues go, will probably have to be thickened. This thickening is called the chimney breast. It is necessary to allow 9 inches thickness of wall on the outside of flues, and $4\frac{1}{2}$ inches in between flues. Thus for a single 9×9 inch flue the chimney breast must be at least 27 inches wide, and the total thickness of wall from back to front must also be 27 inches, *i.e.*, the breast must project 9 inches from an 18 inch wall. For 2 flues, each 9×9 inches, the measurements will be $27 \times 40\frac{1}{2}$ inches. If there are 2 fireplaces back to back on the ground floor, and 2 on the 1st floor immediately above, the wall may be $40\frac{1}{2}$ inches from front to back, and the width of the breast as follows:—$5\frac{1}{4}$ ft. up to 1 ft. below the 1st floor, $5\frac{3}{4}$ ft. from here up to $4\frac{1}{2}$ ft. above the 1st floor, and $40\frac{1}{2}$ inches from here to the roof. The extra width above and below the 1st floor may be arranged for by offsets.

N.B.—The ends of wooden beams should never come close to fireplaces or chimney flues. When the chimney comes out in the centre of the ridge of the roof, the ridge poles should not be built into the chimney wall, but iron brackets should be fixed projecting from the wall, so that they can support the ends of the ridge poles.

C. *Chimney stacks.*

92. The best position for these to avoid leaks in the roof is on the ridge. They should go well above the roof; 4 ft. is advisable. They should generally be covered over the top, and have openings at the sides, which must have a total sectional area of at least $1\frac{1}{2}$ times that of the flues. If the stack is not covered, the flues must curve sufficiently to prevent rain beating directly down on to the fireplace. The openings should be covered with wire netting to prevent birds from building nests inside. If the roof is thatched, the stack *must* be covered, and the side outlets covered with wire gauze of $\frac{1}{4}$ inch mesh to prevent sparks getting on to the thatch.

12. Timber Partition Walls.

93. It may be necessary to make light walls of timber in masonry buildings either:—

A. On ground floors to save money if they are cheaper than masonry.

B. On an upper story for the same reason, or if it is desired to make a wall where there is no supporting wall underneath.

In either case they must bear no weight above. If made on an upper story they should generally be made in the form of a truss, and be supported as far as possible on the masonry walls at each side. When the main frame is complete, planks are nailed over one side. To make the wall better and more sound proof, planks may be fixed on the other side as well, and over the planks on both sides laths (thin strips of split wood $1\frac{1}{2} \times \frac{1}{2}$ inches) with slight intervals between may be nailed. These act as a holding surface for a coat of lime plaster mixed with horse hair or fibre.

13. Staircases.

94. When planning a double-storied building one of the most important points to decide is the best position and the best shape for the staircase. It should if possible be entirely inside the building. It may be straight if there is enough room; otherwise it may have one or more right angle turns or bends according to the space available and the height to be ascended. The arrangement which is most economical of space is the dog-legged with winders, but this should not be used, as the winders will not have enough tread. A dog-legged staircase with a half-space landing is a useful form, or a geometrical staircase may be used with a space between the flights. Various other plans can be adopted, but it is better to avoid winders, if possible.

95. Staircases may be of wood, stone, reinforced concrete, iron, or masonry. The latter may be solid or supported on arches. If suitable stone is available, the steps may be of solid blocks generally supported on walls. Suitably hard stone is always better than bricks for the steps. Wooden staircases are lighter, and do not need such strong supports. The steps are supported on 2 or more inclined beams called strings or stringers, and if there are turns or bends, cantilever beams, or beams supported on posts from the ground, will have to be built into the walls to support the stringers. The stringers are generally $3\frac{1}{2}$ inch planking 10 to 12 inches wide with $1\frac{1}{2}$ inch mortises cut to receive the tenons of the treads. Two wrought iron bolts $\frac{3}{4}$ inch diameter should be fitted across each flight near the top and bottom to hold the stringers firmly together.

The lower ends of the stringers are notched or tenoned to a cross beam or trimmer to give a firm footing. The front face of the stairs consists of vertical pieces of timber called risers. These may be omitted in rough staircases. The rise of steps should be between 5 and 7 inches, and the tread between 9 × 12 inches. The wider the tread the less the rise, and the greater the rise the less the tread. An approximate rule is that the tread × rise should equal 60 to 66 inches (*e.g.*, 5 × 12, 6 × 10 or 6 × 11, 7 × 9 inches). The width of the staircase should not be less than 3 ft., and $3\frac{1}{2}$ to 4 ft. is preferable. A flat landing should be made at every change of direction, and at intervals of every 14 to 18 steps in long straight staircases. If the staircase has to wind, the tread at 16 inches from the handrail must be at least 9 inches wide. Handrails should be $2\frac{1}{2}$ to $2\frac{3}{4}$ ft. above the outer edge of the tread, and $2\frac{3}{4}$ ft. on landings.

14. Doors and Windows.

A. *Doors.*

96. (1) *Door frame or chaukat.*—This consists of 2 upright posts, and a horizontal top sill or lintel, and a bottom sill, fastened together with mortise and tenon joints. The lintel and bottom sill generally project 6 inches to each side and are built into the walls.

The dimensions of the frame timber vary from 3 × 3 to 3 × 4 or 4 × 5 inches according to the size of the door. A rebate is cut round the inside of the frame for the door to fit into when shut. The width of the rebate equals the thickness of the door, and the depth about $\frac{1}{2}$ inch.

97. (2) *Doors.*—Ordinary doors are $6\frac{1}{2}$ to 7 ft. high and about $2\frac{1}{2}$ ft. wide, and $1\frac{1}{2}$ to 2 inches thick. Single leaf doors should not be more than $2\frac{3}{4}$ ft. wide owing to the danger of wider ones warping. If a greater width is desirable, double-leaved doors may be

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used. It is advisable to have double doors to rooms if beds or other large articles of furniture are likely to be taken in and out frequently. The total width of the opening in this case is generally $3\frac{1}{2}$ to 4 ft. All doors should open inwards. The inner edges of double-leaved doors are rebated so as to fit tightly. It is very important to make doors of well-seasoned wood. Frames may be of *sal* wood, but never the doors themselves, for which teak, deodar, or *sissu* (*Dalbergin sissoo*), or other similar timbers are best.

98. (3) *Types of doors.*—(a) *Ledged, or Ledged and braced.*—This is the cheapest type. Vertical planks (called battens in the case of doors) with rebated or tongued and grooved joints are nailed on to 3 cross ledges with or without diagonal braces.

99. (b) *Framed and braced.*—An outer frame the full thickness of the door is tenoned together, and strengthened by a central cross rail and 2 diagonal braces half the thickness of the door. Battens half the thickness of the door fit inside the frame and against the rail and braces. They are either just nailed to the rail and braces or also tongued to fit into grooves in the frame.

In the above 2 types of door the battens are generally of the same thickness as the ledges and braces, or as the rail and braces, *i.e.*, $\frac{3}{4}$ to 1 inch, or half the total thickness of the door.

Battens, ledges, and braces should not be more than 6 inches wide. Ledges and braces are on the inside of doors and battens on the outside. Braces must slope upwards and outwards from the hinged side.

100. (c) *Framed and battened.*—This consists of an outer frame of 4 × 1 inch planks with $4 \times \frac{1}{2}$ inch tongued and grooved battens nailed diagonally across. A 2nd light frame is fixed over the battens.

The above 3 types of doors are called battened doors as distinct from panelled doors.

101. (d) *Panelled.*—These are more expensive, but look nicer than battened doors. The outer frame with rails, etc., is tenoned together and grooved on the inside to receive the panels. Panels are generally of one piece of timber, and shaped so that the centre is about 1 inch thick and the edges $\frac{1}{2}$ inch or less. Cheaper panels are sometimes made of narrow battens tongued and grooved together and fixed at an angle of 45° with the door frame.

102. (e) *Half panelled, half glazed.*—Panelled doors with glass panes replacing the upper panels are often made. The glass panes should not be too small, and the doors should be designed for a size of pane easily obtainable. This also applies to glazed windows.

B. *Windows.*

103. (1) *Casement Windows.*—These are hinged and open like doors, and have either 1 or 2 leaves. For lower subordinates' quarters and godowns, etc., they may be battened and made in the same way as ledged doors. But they are generally glazed. They may open inwards or outwards. If chicks or wire gauze are to be fixed outside, they must open inwards. They may be of any convenient size. A suitable size for ordinary window openings is 3 ft. wide and 4 ft. high. Bathroom windows should be high enough to prevent anyone seeing in from outside, or else frosted panes should be put in. Window frames are generally 1½ inches thick. Window space for living rooms should as a general rule, if possible, be 1 square ft. per 100 to 125 c.ft. of room content; *e.g.*, 1 window 3 × 4 ft. for a room of 10 × 10 ft. and 12 to 14 ft. high.

104. (2) *Swinging windows.*—A single window is swung on 2 horizontal pivots fixed into the sides of the window frame a little above the centre of the height, and resting in sockets cut into the outer frame. Clerestory and other high windows are made in this way, and have cords attached for opening and shutting.

C. *Wire Gauze for Doors and Windows.*

105. This is sometimes fitted outside ordinary doors and windows. In a doorway a separate door is made with an outer frame and 1 cross rail, and with the whole of the centre made of fine wire gauze.

Inner ordinary doors can be opened to let in air, and the gauze doors kept shut to keep out mosquitoes and other insects.

For windows the gauze is generally fastened to a fixed frame.

D. *Weather Boards and Sunshades.*

106. External doors and windows not protected by a verandah or by overhanging eaves, etc., should have weather-boards fitted at the bottom. These are boards slanting downwards and outwards to prevent rain beating in under the bottom.

Similarly a sunshade, which also acts as a rain protector, is fitted over the top. It consists of zinc or iron sheets or planks sloping down and supported by a framework attached to the walls or to the door or window frame. If windows have sunshades, it is probably unnecessary to have weather boards as well.

E. *Fastenings for Doors and Windows.*

107. Hinges are generally of iron. For each ordinary door 3 4- or 5-inch hinges and for windows 2 3- or 4-inch hinges are suitable. Iron drop bolts are fixed on the inside of doors and windows at the top and bottom to secure them from the inside. When bolted for any length of time, both top and bottom bolts should be secured, as this prevents warping. Handles, especially to doors, are necessary for opening and shutting them. They may be wooden knobs, or of metal, and should be on *both* sides. Latches are sometimes fitted for keeping them shut; either sliding wooden ones, or wood or metal ones to lift up. These are not really necessary if drop bolts and handles are provided. Wooden cleats should be fixed for holding doors and windows firmly open without swinging.

15. DRAINAGE.

108. This is important, but is generally neglected. Rain water falling off the roof should be prevented from running down walls, and also from falling too near the base of walls and splashing up on to them. It should also be prevented from sinking in close to the walls, and thus damaging the foundations.

The best method is to have zinc or galvanised iron gutters round the eaves of the roof with vertical pipes at intervals leading down to drains at or below ground level. The gutters should have a slope of at least 1 in 100. This method is generally considered too expensive for most forest buildings.

The next best method is to have shallow open drains round the base of the building to catch the water as it drips from the roof, and lead it away. These drains should have rounded concave bottoms, as this keeps the stream more together, and enables it to carry its impurities along with it more easily than if the bottom were flat and the sides straight up. The slope should be not less than 1 in 50, and 1 in 25 is better. They may be made of brick or stone masonry and lined with cement plaster. If no other drains are made, they should at least be made to carry away water from bathrooms and kitchen, and connect with latrines.

If no drains are made, then a 3-inch layer of metalling (broken stone or brick, etc.) should be rammed round the building for a width of about 5 ft., and with a downward slope of 1 in 30, the surface being made as like that of a metalled road as possible. This will carry away the water and prevent it sinking in too close to the foundations.

When making drainage outlets in the parapet round a flat roof, if no drain pipes are used, zinc or galvanised iron spouts should be fixed to carry the water at least 12 inches out from the walls. Similarly the eaves of a sloping roof should be made to project at least 12 inches beyond the walls.

16. LIGHTNING CONDUCTORS.

109. These should be fixed to all buildings which from their height or exposed position are likely to be struck by lightning. They are not generally considered necessary in forest buildings in the plains, but may be advisable in the hills, especially on exposed ridges. The conductor consists of a solid metal rod projecting freely about 3 ft. into the air above the highest or most prominent point of the building, *e.g.*, a chimney, and connected at its base with a continuous metal rod or strip, which is carried down by as direct a route as possible and without sharp bends over the roof and outside the walls to the ground, in which it is buried for some distance from the building. This conducts the electricity of the lightning safely away from the building. The solid rod at the top should have its end pointed, or better still made into several sharp prongs or points. The usual form used for the metal connecting the rod and the ground is either (1) a tape, *i.e.*, a thin strip, or (2) a rod, solid or of a number of strands, or (3) a hollow tube. The whole conductor should be either of copper or of iron, and must be of the same metal throughout. Iron is 6 times less effective as a conductor than copper, and it is therefore sometimes stated that if iron is used the sectional area of the rod, etc., must be 6 times as great as if copper is used; this being arranged either by using rods of 6 times the sectional area, or by using 6 times as many rods of an equal area. But other authorities say that the relative conductivity does not matter and the sectional area can be the same whether iron or copper is used, the only important point being that the size should be sufficient to prevent it being melted by the electric current. All that is probably necessary is that the minimum size used either for copper or iron should be for tapes 1 inch wide and $\frac{1}{8}$ inch thick, for rods $\frac{1}{2}$ inch diameter, and for hollow tubes $\frac{3}{4}$ inch diameter and $\frac{1}{8}$ inch thick. Much larger sizes are, however, sometimes used.

A conductor protects an area round it roughly of radius equal to its height above ground, and in most forest buildings one will be enough. All metal surfaces in roofs, ridges, door or window coverings, etc., should be connected with the conductor. Any joints must be closely rivetted, or bound very tightly together to prevent water getting between. The overlapping surfaces must be clean and bright.

For buildings with iron roofs it is sufficient to connect the roof covering to earth with iron conductors rivetted to it at the eaves at each corner of the building, or for small buildings at the 2 opposite corners. If a masonry chimney projects, a 6-inch wide strip of iron sheeting may be fixed over the top of the chimney and rivetted to the roof covering on each side. Separate iron verandah roofs must be connected with iron main roofs.

The bottom of the conductor must be taken well away from the building. One or more trenches are dug starting $1\frac{1}{2}$ to 2 ft. deep and 30 ft. lon, and sloping down 1 in 10. The conductor should go along the bottom of the trench, or old iron chains may be laid in them and connected with the foot of the conductor. The end of the conductor should consist of a plate 3 × 3 ft. and not less than $\frac{1}{16}$ inch thick if of copper, or $\frac{1}{8}$ to $\frac{1}{4}$ inch thick if of iron, and buried in a pit in the dampest soil available. The pit and trenches should be nearly filled up with charcoal or coal ashes, with gravel or earth on top.

V. STRENGTH OF TIMBER AND CALCULATION OF DIMENSIONS.

1. STRENGTH OF TIMBER IN RELATION TO THE LOAD IT HAS TO CARRY AND TO ITS DIMENSIONS.

1. Timber used in construction often has to bear a weight, *e.g.*, in roofs or floors of buildings, or in bridges. It must be strong enough to resist the force of this weight or load. It is, therefore, important to be able to calculate the strength of timber and to know:—

(*a*) What sizes of timber are necessary to bear safely a given load, and

(*b*) What load can be borne safely by timber of a given size.

The most important force or strain to which timber in construction is subjected is transverse or cross strain, which tends to bend and finally to break it across. The transverse strength of a beam is its power to resist breaking, and the stiffness of a beam is its power to resist bending or deflection.

2. The strongest beam that can be sawn from a log of a given size has the proportion between its depth (*d*) and its breadth (*b*) 10 : 7.

In other words $\frac{d}{b} = \frac{10}{7}$.

If $b = 1$ then $d = \sqrt{2}$ or 1·4142

If $d = 1$ then $b = \frac{1}{\sqrt{2}}$ or 0·7

The stiffest beam that can be sawn from a log of a given size, *i.e.*, which will bear the greatest weight with the least bending, has the proportion $\frac{d}{b} = \frac{10}{5{\cdot}7}$. But a beam of this section cut from a log of exactly the same size as before will not be quite so strong. The stiffness of a beam is important, but transverse strength is generally more important, and if a beam is strong enough it will nearly always be stiff enough. Therefore, when considering the question of the size of timber necessary in construction, transverse strength alone will be considered.

3. Strength has a definite relation to breadth (*b*) and depth (*d*) and length (L). For any one species of timber the breaking load, *i.e.*, the load which, when applied transversely to a beam, will break it across, is directly proportional to the breadth and to the square of the depth, and varies inversely with the length. Thus the breaking load (W) is proportional to $\frac{bd^2}{L}$. W. is generally given in lbs., b and d in inches, and L in feet.

2. DIFFERENT METHODS OF LOADING.

4. Beams are not, however, always loaded or supported in the same way, and thus W will vary according to the method of loading and support.

A. $W = \frac{bd^2}{L}$ applies when the beam is supported freely at both ends, and has the weight in the middle.

B. When the load is evenly distributed along the beam it requires twice as heavy a load to break it, and $W = 2\frac{bd^2}{L}$.

C. When the beam is fixed at both ends and has the weight in the centre, $W = \frac{3}{2} \times \frac{bd^2}{L}$.

D. When the beam is fixed at both ends and has the load evenly distributed, $W = 3\frac{bd^2}{L}$.

E. When the beam is fixed at one end and has the other end free and has the load evenly distributed, $W = \frac{1}{2}\frac{bd^2}{L}$.

F. When the beam is fixed at one end and has the other end free and has the load concentrated at the free end, $W = \frac{1}{4}\frac{bd^2}{L}$.

5. For practical purposes, however, we do not want to know the breaking load, but the safe load a beam can take. The safe load or working load is generally taken to be $\frac{1}{7}$th the breaking load for timber, and this factor of safety (F), by which the breaking load must be divided to obtain the working load is therefore 7. The formula for (A) above now becomes $W = \frac{bd^2}{FL}$, W now becoming the working load.

3. VARIATIONS IN STRENGTH ACCORDING TO SPECIES.

6. But the strength of timber varies according to the species. To obtain the strength of any particular beam the formula must,

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therefore, include a factor representing the breaking load of that particular species. This factor, called the co-efficient of transverse strength or of rupture (P) is worked out by expert timber testers, and is the load in lbs. which, when applied at the centre of a piece of timber 1 ft. long between supports and 1 inch square in section, will just break it. It varies from about 300 to well over 1,000. The formula thus becomes $W=\frac{bd^2}{FL}\times P$.

7. Values of P for representative species are as follows for seasoned timber:—

Shorea robusta, U. P.	833
Shorea robusta, C. P.	872
Shorea robusta, Bengal	1,067
Terminalia tomentosa, U. P.	854
Dalbergia sissu, U. P.	874
Anogeissus latifolia, U. P.	738
Anogeissus latifolia, Madras	893
Mesua ferrea, Assam	1,337
Dipterocarpus pilosus, Assam	920
Lagerstroemia flos-reginae, Bengal	736
Dillenia indica, Bengal	755
Pterocarpus dalbergioides, Andamans	845
Tectona grandis, Burma	804
Tectona grandis, Burma (girdled)	831
Tectona grandis, C. P.	538
Tectona grandis, Malabar	683
Abies pindrow, Punjab	651
Picea morinda, Punjab	552
Cedrus deodara, Punjab	586
Pinus excelsa, Punjab	498
Pinus longifolia, U. P.	566
Pinus longifolia, U. P. (twisted)	399
Pinus longifolia, Punjab	612

N.B.—For green timber the values are much lower, *e.g.*, U. P. *Sal*, 776, and *Abies pindrow*, 432.

4. USE OF FORMULA FOR CALCULATING SIZE OF TIMBER NECESSARY TO BEAR A GIVEN LOAD.

8. The following example will show how to find the required size of beams when W = the weight they will have to bear is known. A flat balcony $20 \times 2\frac{1}{2}$ ft. weighing 25 lbs. per square ft. and liable to carry a steady load of 75 lbs. per square ft. is to be carried on

5 *sal* cantilevers fixed in the wall. Find b and d for the cantilevers.

F = 7, and the proportion $\frac{b}{d}$ is to be $\frac{0 \cdot 7}{1}$, the method of loading is according to (E).

The working load on each cantilever is $(25 + 75) \times \frac{20}{5} \times \frac{5}{2} = 1{,}000$.

P for *Sal* is 833 or say 830.

The formula is $W = \frac{1}{2} \frac{bd^2}{FL} \times P$.

$$\text{or } bd^2 = \frac{W \times FL \times 2}{P}$$

$$= \frac{1{,}000 \times 7 \times 5 \times 2}{830 \times 2} = 42 \cdot 2.$$

Now $\frac{b}{d} = \frac{0 \cdot 7}{1}$, $\therefore b = d \times 0 \cdot 7$, $\therefore bd^2 = d^3 \times 0 \cdot 7$.

$$\therefore d^3 \times 0 \cdot 7 = 42 \cdot 2$$

$$\therefore d^3 = \frac{42 \cdot 2}{0 \cdot 7} = 60 \cdot 3$$

$$\therefore d = \sqrt[3]{60 \cdot 3} = 3 \cdot 9$$

$$\therefore b = 3 \cdot 9 \times 0 \cdot 7 = 2 \cdot 7$$

Thus to use round figures and to be on the safe side the size of the cantilevers should be 4 inches deep and 3 inches broad.

5. METHOD OF CALCULATING THE LOAD.

9. The difference between dead and live loads is important. A dead load is the fixed or steady part of the load, *e.g.*, the actual weight of a roof. The live load is any suddenly applied or rapidly moving load, *e.g.*, a cart moving over a bridge. A live load produces twice the effect of an equal dead load. Thus twice the strength is necessary to resist it, and the factor of safety must be double. In other words, if a live load actually weighs 100 lbs. it should be considered to be 200 lbs.

10. Loads are generally expressed in lbs. per square foot of surface. In calculating loads on roofs the following are included :—

A. The actual weight of roof above the timber, the size of which is to be calculated.

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B. *Wind pressure.*—This depends on the slope of the roof. Usual allowances are as follows:—

For flat roofs—*nil.*
For roofs with a slope of 1 in 4—14 lbs. per sq. ft.
For roofs with a slope of 1 in 3—17 lbs. per sq. ft.
For roofs with a slope of 1 in 2—23 lbs. per sq. ft.
For roofs with a slope of 1 in 1—35 lbs. per sq. ft.

C. *Rain absorption.*—This depends on the material of the roof. Average allowance is 3 lbs. per sq. ft.

D. *Snow.*—5 lbs. per sq. ft. should be allowed for every ft. in depth of snow likely to lie on the roof. No allowance need be made for roofs with a 1 in 1 slope, or steeper, as the snow slides off at once.

For flat roofs 30 lbs. per sq. ft. should not be exceeded.
For slopes of 1 in 2—20 lbs. per sq. ft. should not be exceeded.

E. Occasional loads; *viz.*, people, etc., on floors of flat roofs, or men doing repairs on sloping roofs. For the first an average of 20 lbs. per sq. ft. may be allowed, though it might go up to 100 lbs. per sq. ft. if crowds of people had to be allowed for. For the second no allowance need be made, as the wind allowance will cover this, because men would not be on the roof doing repairs when a very strong wind was blowing.

6. *Weight of Materials.*

11. For calculating (A) above the weight of various roof materials must be known. Actual weighment of samples is a good thing, but this is often impracticable. The following list is a rough guide:—

Material	*Weight lbs. per square ft.*
Corrugated iron 24 gauge	1½
Corrugated iron 22 gauge	2
Galvanised iron 24 gauge on 1 inch planking	5
Mangalore tiles and battens	10
Single Allahabad tiles and battens	17
Double Allahabad tiles and battens	34
Single country tiles with frames	14
Double country tiles with frames	24
9-inch thatch and frames	10
6-inch thatch and frames	6½

Material	*Weight lbs. per square ft.*
Slates (alone)	5 to 11
Planking, ¾ inch (deodar or pine)	3½
4-inch terrace on 2 layers 1½ inch tiles	100
4-inch terrace on 4-inch brick arches of 3 ft. span	115
Lime or mud plaster ceiling on wire netting	7
	lbs. per cubic ft.
Brick masonry pakka bricks	120
Brick masonry sundried bricks	100
Stone masonry lime mortar	160
Stone masonry, dry	130
Cement concrete	130 to 150
Lime concrete	115
Lime plaster	106
Lime mortar	109
Clay	110 to 130 (average 118)
Loam	110
Rammed earth	100
Sand, dry	100
Sand, wet	110 to 125

For further weights see U.P. Forest Pocket Book, page 306.

	Each. cwt.
Elephants unloaded average	50
Elephants loaded average	72
Camels loaded average	15

Weight of Timber	*lbs. per cubic ft.* seasoned	*lbs. per cubic ft.* green
Shorea robusta, U. P.	56	76
Terminalia tomentosa, U. P.	53	68
Dalbergia sissu, U. P.	50	67
Anogeissus latifolia, U. P.	60	66
Tectona grandis, Burma	40	55
Mesua ferrea, Assam	60	69
Lagerstroemia flos-reginae, Bengal	41	70
Dillenia indica, Bengal	40	59
Abies pindrow, Punjab	33	42
Picea morinda, Punjab	29	42
Pinus, Excelsa, Punjab	32	43
Cedrus deodara, Punjab	36	42
Pinus longifolia, Punjab	38	42
Pinus longifolia, U. P.	33	51

7. Further Example of the use of the Formula.

12. A flat roof of 4-inch terrace on 2 layers $1\frac{1}{2}$ inch tiles is to be laid on *sal* joists 1 ft. apart, and 14-ft. long *sal* beams 6 ft. apart centre to centre. The load to be carried by the joists is:—

	lbs. per sq. ft.
Weight of roof	100
Rain absorption	3
Occasional load	20
Total .	123

The area to be supported by each joist, or section of joist between points of support, is 6×1 ft. or 6 sq. ft. Thus the load is 123×6 or 738 lbs. This weight is W or the working load. The formula in this case will be for loading by method B.

$$W = 2 \frac{bd^2}{FL} \times P.$$

$$\therefore bd^2 = \frac{W \times FL}{2P} = \frac{738 \times 7 \times 6}{2 \times 830} = 18{\cdot}7.$$

$\therefore$ d = 3·0 and b = 2·1 or say 3 inches and $2\frac{1}{2}$ inches.

To calculate the size of the beams:—

The area supported by each beam is 14×6 ft. $= 84$ sq. ft.

The load $= (123 \times 84) + 227\frac{1}{2}$ (weight of joists) $= 10{,}559\frac{1}{2}$.

The weight of the joists is calculated by taking the number of joists as 13, presuming that 6 inches at each end of the beam rests on the wall plates, and that the first joist starts at 6 inches from the wall. The formula is the same:—

$$bd^2 = \frac{21{,}119 \times 7 \times 14}{2 \times 2 \times 830} = 621{\cdot}4.$$

$\therefore$ d = 9·6 and b = 6·7 or say 10 inches and 7 inches.

8. Calculations for Sloping Roofs.

13. In this case calculations are made in the same way for timber bearing direct transverse strain; *e.g.*, in a King Post Truss all timber above the actual truss, *i.e.*, purlins, common rafters, and battens. The truss itself bears no direct transverse strain, the weight above it being carried on its joints. The calculation of the necessary sizes of the parts of the truss is rather complicated and will not be dealt with here. Thus the actual sizes for different spans have been given.

9. Proportion between breadth and depth of beams.

14. It has already been stated that the strongest beam that can be cut out of a log of a given size has $\frac{d}{b} = \frac{10}{7}$ or $1\frac{3}{7}$. But this

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does not mean that beams should always have their dimensions in this proportion. It is true that a beam with $\frac{d}{b}=1\frac{3}{7}$ can be obtained from a smaller log than a beam of equal strength with $\frac{d}{b}$ of any other value. But since the transverse strength of a beam is proportional to b and to d^2, it is economical to have the depth as great as possible in proportion to the breadth, provided logs of sufficient size are obtainable, and provided the extra timber left over out of the log can be utilised. The only limiting factor is that if $\frac{d}{b}$ is too great the beam will be liable to warp and fall over on its side.

15. As an example of the economy effected by increasing the value of $\frac{d}{b}$, the previously quoted example may be taken, where *sal* beams of 10 × 7 inches were to be used. If $\frac{d}{b}$ is taken as 3, the dimensions would be approximately $12\frac{1}{2} \times 4\frac{1}{2}$ inches. bd^2 in each case is about 700, which means that the beams are of equal strength. But bd, or the sectional area, is 70 and 56, so there would be a great saving of timber in the latter case—$1\frac{1}{4}$ c.ft. in each beam.

16. The following table gives an idea of the proportions generally used, the figures being the values of $\frac{d}{b}$:—

Kind of timber.	Slope of floor or roof.		
	Flat.	1 in 2.	1 in 1.
Roof battens	2	$1\frac{1}{4}$ to $1\frac{1}{2}$	1
Beams, purlins, and floor joists	3 or 4	2	1
Rafters	...	2 or 3	2 or 3
Ridge poles	...	3 or 4	3 or 4
Wall plates	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$
Bressumers (Post plates)	2	$1\frac{1}{2}$	1

If $\frac{d}{b}$ is greater than 3, and beams are not fastened by planking on top, timber packing blocks should be built in at the ends to prevent them turning over, or X braces may be used.

b. should not as a rule be less than 2 inches, unless the grain is very straight. Battens under tiles, etc., are sometimes made smaller. Timber columns, *i.e.*, vertical pieces under compression or tension, are usually square in section.

10. STRENGTH OF ROUND TIMBER.

17. If round timber is used, as is often the case in forest bridges, the strength is calculated from the radius of the circular cross section instead of from the breadth and depth. If this radius in inches = R., then $4{\cdot}7\ R^3$ is substituted for bd^2 in the formula, which then becomes W (working load) $= \frac{4{\cdot}7\ R^3 \times P}{FL}$.

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VI. PREPARATION OF ESTIMATES.

1. When it is proposed to construct a building or bridge or other work, it is necessary to decide on the exact plan, the quantities of materials required, and the cost of construction. An estimate must therefore be prepared.

1. Summary of the Different Parts of an Estimate.

A. *Report.*

2. This gives the necessity for or object of the work, a general description of it, the exact site, the nature of the foundation bed, and any special reasons for the type or design adopted.

B. *Specifications.*

3. This lays down briefly and clearly the nature and quality of the work required and of the materials to be used in the various parts of the work. Mention should also be made of any special conditions to be observed in the execution of the work.

C. *Details of Measurements.*

4. This is a tabular list showing actual measurements and the volume or number of all materials in all parts of the work in detail. The size and number of the parts and the total contents in cubic feet should be given. Various items should be grouped under separate headings, *e.g.*, for a building:—earthwork, brick masonry, roofing, woodwork, etc. Dimensions are taken from the plans.

D. *Abstract of cost.*

5. This is a tabular statement showing the total quantities of each kind of work, and the rate per unit of measurement, and the total amount for each head. The cost of materials and estimated cost of transport should, when necessary, be shown separately.

When the total estimated cost is obtained, something should be added for possible increases in cost due to changes in design or other unforeseen expenditure. This amount is generally 5 per cent. of the whole cost and is called "contingencies". When 5 per cent. for contingencies is added in this way, no extras should be added for contingencies under individual subheads.

E. *Plans.*

6. These are drawings showing the size and shape of the work. They must be drawn to scale and show dimensions. A scale must always be given, and it is generally advisable to show the north point. In the case of a building the drawings include:—

(1) A ground plan.
(2) One or more elevations showing the outside of the building.
(3) One or more vertical sections.
(4) Detailed drawings of particular parts on a larger scale, if they cannot be shown in sufficient detail in the other drawings.

A suitable scale is for (1) to (3) 1 inch = 8 feet, and for (4) a larger scale according to needs.

Drawings are very important. They must be accurate and clear, so that detailed measurements can be taken off them, and so that they can be understood easily by other people.

2. FURTHER DETAILS CONCERNING THE PARTS OF AN ESTIMATE.

7. These refer to buildings, but most of them also apply with the necessary modifications to other works.

A. *Report.*

This will vary according to circumstances. It will generally be short, and in the case of small and unimportant buildings it may often be combined with the specifications.

B. *Specifications.*

8. This should be drawn up under separate headings for each separate type of work; *e.g.*, earthwork, concrete in foundations, masonry, roof, floor, woodwork, etc. Such details as are considered necessary should be given; *e.g.*, in the case of concrete or mortar, the quality and proportions of ingredients and the necessary particulars regarding mixing and laying. For a roof, the type of roof should be given with any other necessary details, *e.g.*, " Flat terracing supported on *sal* beams as shown in the section ". Particulars regarding the supply of raw materials may also often be necessary.

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It is unnecessary to give details that can be shown in the drawings or that are given in the details of measurements, such as class of bricks, depth of foundations, height of plinth, thickness of walls, etc.

C. *Details of measurements.*

9. (*a*) *Form to be used.*—The following form, modified to suit requirements, if necessary, should be used:—

DETAILS OF MEASUREMENTS.

Particulars.	No.	Measurements.			Deductions.	Contents.	Total of each.
		Length.	Breadth.	Height or depth.			
1. Earthwork—							
(*a*) Excavation—							
Long walls .	2	22½	2½	1	...	113	
Short walls .	2	17½	2½	1	...	88	201 c. ft.
(*b*) Rammed Earth.							
2. Concrete.							
3. Brick Masonry—							
(*a*) Foundation.							
(*b*) Plinth.							
(*c*) Superstructure.							
Long walls, etc. .	2	22	2	12¾	...	1,122 etc.	
Deduct:—						2,313	
Doorways .	2	4	1½	7½	90	...	2,223 c. ft.

10. The above gives examples of a few entries. The usual order of items is as follows:—

(1) Earthwork—

(*a*) Excavation including any necessary levelling of the site.

(*b*) Rammed earth.

(2) Concrete in foundations.

(3) Masonry in foundations, plinth, and superstructure, including archwork, fireplaces, chimneys, etc. The different types of masonry should be separated under subheads, *e.g.*, 1st class bricks in lime mortar, and 2nd class bricks in mud mortar.

(4) Plaster.

(5) Pointing.

(6) Whitewashing.

(7) Roofing.

(8) Flooring.

(9) Woodwork, including beams and other roof timbers, doors, windows, etc.

(10) Ironwork.

(11) Painting.

(12) Any other miscellaneous items.

11. (*b*) *Points to note in measuring.* (1) *Earthwork, concrete, and masonry.*—In rectangular buildings the external length of long walls and the internal length of shorter cross walls should be measured.

The same should be done for the foundation trenches. The difference in dimensions due to offsets should be carefully noted. Masonry should be measured first neglecting the door and windows, etc., and then all openings should be calculated separately and deducted. If archways, jambs of doors, etc., are to be made in better class masonry at a higher rate, these must also be calculated separately, and separate entries made after deducting them from the mass of masonry. There are several ways of measuring the masonry in arches:—

12. I. For small arches up to 6 ft. span, instead of giving a special rate for arch masonry, the following may be done:—For an ordinary doorway $\frac{1}{3}$ of the opening may be allowed to count as masonry for each arch over it. If there is both a flat and relieving arch over it, $\frac{1}{3}$ of the opening may be deducted and $\frac{2}{3}$ allowed as masonry to cover the extra cost of the arch masonry. Window openings, if not more than $\frac{1}{3}$ of an ordinary door opening, need not be deducted. For small arched openings a deduction in to the springing line may be made.

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13. II. If there is a special rate for arch masonry, the arch masonry may be measured in either of the two following ways:—

(*a*) The length of the arc round the centre of the thickness of the arch between the soffit and the extrados may be measured and multiplied by the thickness and the depth.

(*b*) The inner and the outer radii may be measured, *i.e.*, to the soffit and extrados. The inner and outer circle areas may be worked out from the formulæ:—Area $= \frac{\pi d^2}{4}$ or πr^2. One is then subtracted from the other. The result, which equals the surface area of a ring of which the arch is a segment, is then multiplied by subtending angle between the 2 radii confining the arch segment ÷ 360°. This sectional area of the arch is then multiplied by the depth of the arch from face to face. This gives the cubical contents of masonry in the arch.

Round pillars should be measured as if square, taking the diameter as the side of the square.

14. (2) *Plastering.*—The superficial area in square ft. is taken, the outer and the inner being kept separate as a rule, as rates are often different, and the inner may be whitewashed or colour-washed and the outside not. Plastering is generally calculated for the whole face of the wall, and openings deducted for one side only. The extra allowed for the other side is to cover the cost of plaster in jambs, soffits, and sills, which are not calculated separately.

(3) *Pointing and Whitewashing.*—As for plastering.

(4) *Flooring and Roofing.*—The superficial area is taken in square ft. Roofing includes only the roof covering, *e.g.*, tiles, corrugated iron, shingles, etc. It may sometimes be necessary to calculate the quantities of materials separately, *e.g.*, for a terraced or arched roof, the amount of masonry and concrete, etc.; but generally a definite rate will be fixed for each type of roof per 100 square ft.

(5) *Woodwork.*—This is calculated in cubic ft. to one decimal place for beams, rafters, etc., and superficially in square ft. for doors and windows.

(6) *Ironwork.*—Generally calculated by weight, or in the case of certain articles at so much each. If there is much ironwork and

elaborate calculations are necessary, calculations should be made as follows:—

First in lbs. or seers per running ft., then the weight of each item in lbs. or seers, and finally the total in cwts. or maunds, *e.g.*:—

Particulars.	No.	Length.	lbs. per running ft.	Total.	Grand total.
2¼ inch bolts .	18	⅔	13·27	159·2 lbs. etc.	10·25 cwt.

(7) *Painting, etc.*—Calculate surface area to be done in square ft.

(8) *General.*—It is unnecessary to give quantities to decimal places except for woodwork and ironwork. Measurements are generally in feet unless shown otherwise.

D. *Abstract of Cost.*

15. This may be given in the following form:—

Item No.	Quantity.	Particulars.	Rate.	Per	Amount.	Total.
			Rs. A.		Rs. A.	Rs. A.
1 (*a*)	878 c.ft.	Earthwork, excavation	7 8	1,000	6 9	
1 (*b*)	512 c.ft.	Earthwork, rammed .	10 0	1,000	5 2	
2	433 c.ft.	Concrete . . .	22 12	100	98 11	
..	..	....	..	..	..	
6	1,098 sq. ft.	Whitewashing . .	0 6	100	4 2	
..	..	....	..	..	..	
9	55·5 c.ft.	*Sal* woodwork . .	4 4	foot	235 14	
..	..	....	..	..	..	
10	2·12 cwt.	Ironwork . . .	20 0	cwt.	42 6	
..	..	....	..	..	..	
12	4 no.	Sunshades . .	20 0	each	80 0	
						1,250 0
		Add contingencies Rs. 5 per 100 .				62 8
		Total estimated cost . .				1,312 8

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16. Rates are usually fixed as follows:—

Earthwork	at so much per 1,000 c.ft.
Concrete	at so much per 100 c.ft.
Masonry	
Pointing	at so much per 100 sq. ft.
Plastering	
Whitewashing	
Painting, etc.	
Roofing	
Flooring	
Woodwork—	
Beams, rafters, etc.	at so much per c.ft.
Doors and windows	at so much per sq. ft. or each.
Ironwork	at so much per cwt. or maund or each.

17. A local schedule of rates is generally available. If it is not, and if rates have to be fixed, any rate to be fixed will have to include all or most of the following:—Cost of raw materials, carriage to site, labour in construction, and a fair profit to the contractor if employed. Woodwork will, for instance, include:—Felling trees, sawing or other conversion, carting to site, and carpentry including fixing in position.

The rate for earthwork may depend on the nature of the soil, the lift or depth from which it has to be dug, the lead or distance it has to be carried, and the cost of labour (rate per day per coolie).

E. *Plans.*

18. (*a*) *General.*—It must be emphasised, to start with, that no amount of printed instructions can possibly teach a student how to draw plans. Knowledge of this can only be acquired by much practice, helped by a study of actual plans, and by verbal instruction and demonstration. The following notes are only meant to give a very general idea of what is required, combined with a few hints as to details of procedure.

As full details as possible should be given of dimensions in feet and inches, so that the quantity of each class of work can easily be calculated from them. Total outside dimensions should be shown conspicuously on the ground plan, and heights of walls, etc., in elevations and sections.

In all drawings a fine-pointed, hard pencil, or a pen with a fine nib, should be used.

19. (*b*) *Ground plans.*—The plan is made at plinth level showing the width of the walls immediately above the plinth. The width of the plinth and foundations may also be shown by dotted lines, but this is not generally done, as it makes the drawing confusing. If the building is double-storied, a separate plan of the upper story is necessary.

In showing doors and windows it is a good thing to indicate which direction they are to open if there is room to do so in the plan.

Roof timbers may, if necessary, be shown over the ground plan in a different colour, *e.g.*, red, and either with dotted lines or continuous lines.

20. (*c*) *Elevations.*—An elevation shows the outside of the building exactly as it will appear from one particular direction. It shows one complete face of the building from ground level upwards. It is usual to show the front elevation, and this may be enough. But if there are special details at the sides or back, which it is considered necessary to show, side or back elevations may also be drawn.

21. (*d*) *Vertical sections.*—A section shows a part of the building in elevation, but instead of showing the outside of it, it shows the interior construction along one or more vertical planes. For example, if a section is to be drawn from one side, one or more straight lines are drawn through the ground plan of the building from front to back to represent the position of the section. It is necessary to imagine this line as cutting the building into 2 parts.

The section will then represent exactly what would be seen of the further part of the building if the nearer part were removed. A section should show this part of the building in elevation completely from the foundation bed upwards.

The great advantage of a section is that it can show details which cannot be shown in any other way. For instance, where it cuts through walls, the width and depth of the concrete footing and of the different portions of the foundation wall, and of the plinth can be shown, and if it cuts through a fireplace it can show the shape of the fireplace and flue, etc.

The position of a section should be chosen so as to show as many of the important constructional details of the building as possible, and so as to give as good an idea as possible of the construc-

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tion as a whole. For this reason it is often an advantage for the section line not to be in one straight line, but to be made up of a series of 2 or more lines at different distances from the outside edge of the building. It may also be advisable to draw more than one section, *e.g.*, one from one side, and another from the back, *i.e.*, at right angles to the first one.

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VII. ROADS.

1. GENERAL.

1. Forest roads are made both for transport of timber and other forest produce, and as a means of communication between different parts of the forest. Their importance is very great. Good extraction roads make a great difference to revenue received for forest produce; and in extreme cases timber of valuable species may be worth nothing owing to lack of roads or other means of extracting it. Good communications in the forests also mean increased efficiency, as inspection of work can then be quicker and more frequent.

2. CLASSIFICATION.

2. (1) *Main Cart roads.*—Between forest and railhead or other important centre. May sometimes go through forest as in Dehra Dun. Generally made and maintained by District Boards or the Public Works Department, and only occasionally by the Forest Department. Very often metalled, though in many cases still made only of earth. Width varies from 12 ft. to 25 ft. or more. If metalled, metalling generally 12 ft. with earth backing on each side.

(2) *Forest Cart roads.*—Inside the forest or between different blocks of forest, acting as feeders to main roads. Almost always made and maintained by the Forest Department. Generally earth roads, or in hilly and stony country a mixture of earth and stones or gravel. Width generally 12 ft.

(3) *Forest Motor roads.*—In and near the plains earth motor roads 12 ft. wide are nowadays constructed by the Forest Department for communication through the forests and between different blocks of forest. They often follow the line of cart roads, either side by side with them, or better still where possible parallel and separated by a small strip of forest. Where made entirely of earth, it is important to metal places where cart roads cross them.

(4) *Bridle Paths.*—Generally confined to hilly country, and used only for foot passengers and pack animals. Width varies from 6 ft.

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to 10 ft. They can be made steeper than cart roads, and are therefore shorter, and in many parts of the hills take the place of cart roads where it is impossible or too expensive to make the latter.

(5) *Inspection Paths.*—Narrow tracks generally about 2 ft. wide, and for use for men only, though it is often convenient if they can be made passable for elephants or ridden horses as well. They are for inspection of special works such as plantations, and to make patrolling of the forest by subordinates easier in places where it is not worth making a cart road or bridle path. They must be cheap. They can be much steeper than bridle paths, and extra length is unimportant if money can be saved by going round obstacles.

(6) *Temporary roads.*—For extraction of timber for one or for a few years only; or across wide river beds in the plains for the dry season only. They must be cheap, and should go round hills, etc., if by doing so expensive cuttings and embankments are avoided. It is important to avoid steep uphill gradients in the direction the load will be taken.

3. Alignment.

3. (1) *General.*—Fixing the line along which a road will go is almost the most important part of road making, especially in hilly country, and it is very important to get the best possible alignment before the road is constructed. A good alignment means a saving in cost of construction and maintenance, and traffic along the road will be able to go quicker and more easily, and thus at less cost; and if in future an earth road is to be improved and made into a main metalled road, it can be done without the trouble and expense of a new alignment.

4. (2) *Gradient.*—This is the most important factor which affects the alignment. Gradient or longitudinal slope is generally expressed either by the horizontal length in which a rise of 1 ft. takes place, *e.g.*, a gradient of 1 in 20, or by the number of degrees of elevation above a horizontal plane, *e.g.*, a gradient of 3°. When aligning a road various instruments are used to measure the slopes in order to fix the alignment at the desired gradient. Abney's level shows the slope in degrees, and others such as De Lisle's clinometer show it as 1 in 20, etc. It is also often laid down that the total rise in a mile of length must not be more than so many feet.

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The following tables will therefore be useful:—

GRADIENT.

In degrees.	In horizontal length per foot of rise.	In feet per mile.
1	1 in 57·3	93
1½	1 in 38	139
2	1 in 28·6	182
2½	1 in 23	230
3	1 in 19·1	278
4	1 in 14·3	377
5	1 in 11·4	480
6	1 in 9·5	556
7	1 in 8	660
8	1 in 7	754
9	1 in 6	880
10	1 in 5·5	960

In horizontal length per foot of rise.	In degrees.	In feet per mile.
1 in 5	11° 32′	1056
1 in 7½	7° 40′	704
1 in 10	5° 45′	528
1 in 12	4° 47′	440
1 in 13	4° 24′	406
1 in 15	3° 49′	352
1 in 20	2° 52′	264
1 in 25	2° 18′	211
1 in 30	1° 55′	176
1 in 40	1° 26′	132

N.B.—In these notes all slopes for roads, side slopes for cuttings and embankments, and batter for retaining and breast walls, are expressed in the same way, *viz.*, 1 in 20, 1 in 2, 3 in 1, etc., the first figure being the vertical rise and the second figure the horizontal distance.

5. Gradient is important because the steeper the slope the less the load that can be carried in carts or on pack animals, and there is a limit of steepness for each class of transport beyond which they will not be able to go at all. One steep slope on a road will generally mean reducing the loads which will be carried along the whole length of the road.

6. The steepest gradient considered advisable for any particular class of road is the ruling or maximum gradient. This ruling gradient should never be maintained for very long distances, as it

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is very tiring to animals. A stretch of road with the maximum gradient should always be followed by one with a much gentler slope. Thus the average gradient will always be less than the ruling gradient. Ruling and average gradients for cart roads and bridle paths are generally as follows:—

Cart roads—

Ruling, 1 in 15 over distances not exceeding 300 ft.
Average 1 in 20 to 1 in 25.

The rise per mile is often fixed at a maximum of 240 ft.

Bridle paths—

Ruling, 1 in 6 over distances not exceeding 300 ft.
Average 1 in 7 to 1 in 10.

The rise per mile is often fixed at a maximum of 750 ft.

Inspection paths are aligned by eye, and a ruling gradient cannot be fixed.

7. (3) *Method of Alignment.*—(a) *Preliminary reconnaissance.*—If possible get a good map with contours and study it carefully, noting in particular the main ridges and streams and any especially steep ground. In hilly country consider first the object for which the road is required. If chiefly for timber extraction it should follow valleys rather than ridges, and be as near as possible to the lower boundary of the working area. Bridle paths and other roads used chiefly for communication should follow tops of ridges where possible, so as to have better drainage throughout the year, and to be cheaper by avoiding stream crossings. It may be helpful to try and mark the general alignment on the map. The theoretical average gradient in a straight line between two obligatory points past which the road must go may be worked out by dividing the difference in height by the distance between them. If this average is below the ruling gradient allowed, and there appear to be no impassable obstacles in the way, it may be possible to keep the alignment fairly straight, always remembering that the gradient between two obligatory points should be as even as possible, and not go up and down unnecessarily. If, however, this average gradient is too steep, or there are impassable obstacles, the alignment will have to be lengthened. A method of marking a rough alignment at a given gradient on a contoured map is, *e.g.*, with 20 ft. contours and gradient 1 in 20 (or 20 ft. in 400 ft.), to separate the points of a pair of compasses or dividers to the distance apart representing

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400 ft. on the map, put one point on a contour line and the other point on the next contour line and join the points. This shows a line at a slope of 1 in 20. The above methods are very rough, and will not be much use in very broken ground.

8. After studying the map, go over the ground, and before using any instruments walk over the proposed route several times each way, map in hand, and pay special attention to broken ground, stream crossings, and possible alternative routes. Take with you a local subordinate or villager who knows the ground. Existing paths or old abandoned routes may be of use. Note which side of a ridge is steepest, and look out for precipices and other obstacles. Avoid unstable ground where landslips may occur. The dip of strata may indicate this. During this preliminary reconnaissance, although instruments should not be used systematically, the necessary ruling gradient should of course be borne in mind, and if necessary tested with an instrument occasionally.

9. *Obligatory Points.*—After thorough examination of the ground fix any obvious obligatory points through which the road must pass, *e.g.*, lowest saddles on ridges, best crossings of streams, or special objects the road must reach, such as plantations or villages. Other obligatory points may have to wait till gradients are tried.

10. *Deviations.*—To join two obligatory points the shortest possible route is best as a rule, but a straight line in any but level country is not generally the easiest and cheapest, because to avoid too steep a gradient deep cuttings through hills and high embankments across valleys would probably be necessary. It is therefore often better to lengthen the road by going round such places. Small deviations from the straight do not add a great deal to the length. In some cases a road round a hill may actually be shorter than one over the top. In any case a considerable detour is justifiable to avoid an unnecessary ascent. A common rule is that a detour should be made when the increase in length is not more than 15 times the height saved; *e.g.*, to avoid a hill 100 ft. high, a detour which will be 1,500 ft. longer may be made. Detours may also be advisable to go past a spring or other water supply, or in the case of metalled roads to go past a stone quarry. They may also be necessary to avoid unstable or precipitous ground, or other obstacles.

11. *Alternative routes.*—The comparative advantages of various alternatives should be carefully considered. As well as the comparative gradient and length, the probable cost of construction and of maintenance should be considered. If the amount of traffic is sufficient, it may justify the extra cost of making cuttings necessary for a shorter and less steep road, which will mean a saving in cost of transport. The best line will probably be a compromise between length, cost and gradient.

12. (b) *Actual alignment.*—When the probable final line has been chosen, mark it roughly on the ground by blazing trees, or by any other suitable temporary means. The actual alignment with instruments can then be started.

13. *In Level Country* it does not generally present much difficulty. It can generally be straight for considerable distances; but to break the monotony, make slight curves at least every 2 or 3 miles. Long stretches of absolutely level alignment should, if possible, be avoided, and a minimum slope of 1 in 120 (0° 29′) should be aimed at to facilitate drainage and prevent surface water being held up.

When there are no obstacles compass bearings can be taken off the map, and the centre line of the road demarcated with a prismatic compass and ranging rods. If working in dense jungle bearings should be checked about every 100 yards, because if an error is introduced and not corrected, it will become greater the further the line proceeds. The chief points to remember are to keep on high well-drained ground as much as possible, to avoid swamps and low-lying places and unnecessary crossing of streams and of natural drainage channels. The country should be studied in the rains as well as in the dry weather, or careful enquiries made from local villagers, so as to find out the probable height of floods and the direction of natural drainage. Thus, if it is necessary to cross low-lying ground, the necessary height of embankments and the position of bridges and culverts can be fixed.

14. *In Hilly Country* the alignment will be much more difficult. The first thing to do is to check the gradients of the rough alignment with an instrument. The more difficult and broken ground should be done first, and it is generally best to start at the highest obligatory point and work downwards, as the upper slopes are generally steeper and offer less choice of routes. In certain cases, however, if the ground is very broken and the jungle dense, it is easier to see obstacles such as precipices from below, and the alignment can be made more easily uphill. As a general rule, first get out of difficult ground on the ruling gradient, and then join up sections

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on easier ground with gradients as even as obstacles will permit. When a start is made from an obligatory point, a trial line should be laid out at the desired gradient, keeping as near as possible to the preliminary alignment. Temporary pegs should be put in along the alignment at intervals of not more than 100 ft.

15. *Trial Lines.*—If the preliminary alignment has been carefully made, it may be possible to keep to it. But it will generally be necessary to depart from it, and unforeseen difficulties will probably arise. Thus several trial lines will probably be necessary, and after careful comparison the best one should be chosen. Selection of the final line will depend on the various factors already detailed under preliminary reconnaissance.

16. *Other points to note during alignment.*—The pegs marking the line in hilly country will indicate the outer edge of the road, as it is generally best to cut the whole width of the road out of the hillside. Thus when going round salients the centre line of the finished road will be shorter and steeper than the actual line laid out. If the alignment is being made on the ruling gradient, allowance should be made, and the instrument set at slightly less than the ruling gradient, *e.g.*, 1 in 22 instead of 1 in 20.

A prismatic compass survey is generally of no use in the hills, but in very dense jungle, where natural features are not prominent or easily defined from the map, a straight line along the magnetic bearing between 2 obligatory points and marked by blazed trees may form a useful guide. Other points to note are that the alignment must be level at the site of bridges and culverts, and if possible for at least 20 ft. on each side of them. On sharp curves round spurs the line should be level or nearly level. The gentler the curve the steeper may be the gradient, and if the road is to keep more or less to the contours it will normally go upwards to the end of the spur and downwards the other side into the next re-entrant. At suitable intervals, especially near watering places, wide level halting places should be allowed for, so that carts do not halt on the road.

17. *Laying out curves.*—Curves must be as gentle and regular as possible. The normal minimum radius of curves for cart roads is 50 ft., but in the hills sharper bends may often be necessary, either where a zig-zag is unavoidable, or where too expensive cuttings would be necessary to prevent them. In these cases curves of 30 ft. radius and occasionally less may be allowed for cart roads,

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and of 6 ft. for bridle paths. In such cases cart roads must be made wider round the curves to enable loaded carts to pass easily. The necessary width for a 12 ft. road will generally be from 18 ft. to 24 ft. depending on the actual radius of the curve. Particular care must be taken at re-entrant curves that the longest log likely to be carted (say, 30 ft.) can get round easily. This can be tested during construction by carrying a 30 ft. bamboo or pole along the centre of the road keeping it horizontal and about 3 ft. off the ground.

For motor roads in the plains curves should, if possible, have a much greater radius than 50 ft.

Curves in forest roads are generally laid out by eye by trial and error. But in important cases they can be aligned with any particular radius without the use of instruments by offsets. All that is required is a tape measure and a string of given lengths and a few pegs. (See Lloyd's Engineering, pages 71, 77 and 78.)

Hairpin bends or zig-zags should, if possible, be avoided even on bridle paths. They are bad for traffic and expensive to construct and keep up. They can often be avoided, *e.g.*, at the end of long ridges by starting the descent some way back along the ridge. They are sometimes, however, unavoidable. If possible select sites for them which are fairly level or less steep. These will be indicated on maps by greater distance between contours. The road at the bend must be level, and this will probably mean cutting deeply into the hill for the upper part of the turn, and embanking and revetting the outer side. Or in the case of a bend round a narrow spur, it may mean embanking and revetting both sides.

18. *Demarcation of alignment.*—Trial lines may be marked with rough bamboo or wooden pegs, but along the final alignment permanent pegs must be put in, so that they will last till the road is constructed, which may be a year or more later. Two kinds of pegs are generally used:—

(1) Numeral pegs—3 ft. long and of durable heartwood, pointed and driven in at least one ft. with a wooden mallet. They must be put in at each angle or change of direction, on both banks at bridge sites, and each must be clearly visible from the next. They must not be more than 100 ft. apart, and in uneven ground and on curves will be much closer. Each peg will have a serial number, and the gradient to the next peg marked below the

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number. At the sites of 2-sided cuttings or embankments the depth of cutting or height of embankment required will also be written on them.

(2) Grade pegs—6 to 9 inches long driven in flush with the ground alongside each numeral peg. They show exact level of proposed road, being along outer edge of hill side roads and along centre on level ground. At 2-sided cuttings or embankments grade pegs cannot be put at the proposed road level, and only numeral pegs are used.

When the pegs have been put in, a one-foot trace is cut along the whole length at the exact level of the proposed road. When any tree, etc., which would be expensive to remove, comes in the line, the trace should stop and commence again from the other side, and should not be carried round the obstacle.

4. Preparation of Road Estimate.

19. (1) *General method and Forms to be used.*—When aligning a road it is necessary to obtain an estimate of the probable cost of construction. Earthwork in cuttings and embankments to be made must be measured, the amount of jungle clearing and uprooting of trees, etc., and the number and cubical contents of retaining and breast walls must be calculated, the sites of bridges and culverts with their estimated span must be fixed, and the extent of drainage works necessary must be calculated. For this purpose a form is necessary. This will be filled up from detailed measurements made and information collected in field books at the time.

20. A sample of a suitable form to use for earth roads is as follows:—

DETAILS OF MEASUREMENTS.

Peg No.	Distance.	Earthwork.						Uprooting and clearing.		Gradient.		Forward Bearing.	Remarks.
		Cutting.			Embankment.								
		Sectional area at peg.	Mean of two sections.	Cubical contents.	Sectional area at peg.	Mean of two sections.	Cubical contents.	Trees over 12″ diam.	Bamboo clumps.	Rise.	Fall.		
	Feet.	sq. ft.	sq. ft.	c. ft.	sq. ft.	sq. ft.	c. ft.	No.	No.				
1	...	35	...	...	...	...	...	...	...	...	...	...	...
	30	...	40	1,200	...	...	...	2	...	1°30′	...	...	...
2	30	45	...	...	...	...	...	...	...	...	...	...	...
	50	...	23	1,150	...	...	...	2	1	level		...	...
3	80	0	...	...	...	...	...	...	...	...	...	...	...
	90	...	...	S. D.	...	...	...	3	2	level		...	...
4	170	0	...	...	0	...	...	...	...	...	...	...	...
	40	...	...	...	...	20	800	1	...	...	0°30′	...	...
5	210	...	...	...	40	...	...	...	...	...	...	...	...
105	5,280	50	...	...	...	...	...	...	...	...	...	...	...
Totals 1st mile	5,280	...	...	80,745	...	...	3,260	95	15	...	...	...	...

Pegs are serially numbered throughout the alignment, and there must be a peg at the end of each mile, when an abstract of amounts and estimated cost is made.

21. A suitable form for this is as follows:—

No. of mile.	Abstract of cost.													
	Earthwork.						Jungle clearing cost per mile.	Grubbing out trees over 12″ diameter and bamboo clumps.			Bridges and Culverts.			Total cost per mile.
	Excavation and Embankment.			Surface dressing.										
	Cubic feet.	Rate per thousand c. ft.	Cost.	Length in feet.	Rate per hundred running feet.	Cost.		No. per mile.	Average rate per stump.	Cost.	Span.	Rate per running foot.	Cost.	
		Rs.	Rs.		Rs. a. p.	Rs.	Rs.		Rs.	Rs.		Rs.	Rs.	Rs.
1st .	84,005	7	588	1200	0 12 0	9	40	95	1	95	1 bridge 15′	15	225	1,149
											4 culverts 6′	8	192	
2nd .	57,495	7	403	1750	0 12 0	13	50	70	1	70	3 culverts 10′	8	240	776
Totals .	141,500	...	991	2950	...	22	90	165	...	165	...	...	657	1,925

Estimated cost Rs. 1,925
Drainage and contingencies at 15 % Rs. 289
Total Rs. 2,214

N.B.—Columns for retaining and breast walls can be added if required.

22. (2) *Measurement of earthwork.*—This is done by calculating the sectional area at each peg, and multiplying the mean of each two consecutive sections by the distance between them. When an embankment changes to a cutting there will be a peg at the point of change at which there will be no earthwork. If the sectional area at the next peg where there is either cutting or embankment is, say 30 sq. ft. and the distance is 40 ft., it is usual to take $\frac{1}{3}$ the sum of the two sectional areas and multiply by the distance, *viz.*, in this case $\frac{30}{3} \times 40 = 400$ c.ft. This is more accurate, but is not always done, as great accuracy is not required.

Measurement at the time of alignment is only an estimate for budget purposes, and when the road is constructed actual work done is measured again for payment. In any case digging of earth is very cheap, and great accuracy in measurement for the estimate is not necessary, and rough methods giving approximate results are generally sufficient for forest roads.

Methods differ according to whether the sectional area to be measured is triangular, as generally on hill roads with outside pegging, or is a 2-sided cutting or embankment with centre pegging, as generally in the plains and more level sections of hill roads.

(A) *Triangular cuttings in hill roads.*

23. For important roads over 12 ft. wide the cross slope has to be measured, and from this and the back slope and the road width the sectional area is obtained from earthwork tables (see page 57 of the Manual of Forest Mensuration—the first method described). But for ordinary roads of 12 ft. width or less, a quicker and easier method is with a slope template. This consists of a vertical pole 8 to 10 ft. long and graduated in ft. and half ft., with a moveable arm 9 to 11 ft. long hinged to the base of the pole. Near the top of the arm is a wire or cord which passes through a hole in the top of the main pole and ends in a ring or loop, which fastens to one of the pegs or hooks fixed in the pole at such heights that by pulling the cord tight the arm may be set at slopes of 1 in 1, 2 in 1, 3 in 1, etc., in relation to the horizontal. Another separate pole is required, 16 ft. long and marked at 12 ft. for 12 ft. wide cart roads, or 10 ft. long marked at 6 ft. for 6 ft. wide bridle paths. To measure a triangular section for a 12 ft. cart road with back slope, say, 3 in 1, put up the vertical pole on the grade peg with the arm inclined towards the hillside and set to correspond with the back

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slope. Then hold the other pole up horizontally so that one end touches the hillside and the 12 ft. mark touches the sloping arm. Read to the nearest 6 inches the height at which it cuts the vertical pole—say, 8 ft. The road width multiplied by half this height = cross-sectional area; *i.e.*, 12 × 4 = 48 sq. ft. If the side slope is very steep, and the vertical height of the cutting is more than 10 ft., hold the horizontal rod so that the distance between the side slope and the arm is half the road width. The resulting section should be multiplied by 4. This is not so accurate, but will do. If part of a hillside road has to be banked up, as may occasionally happen, the sectional area of the banked up portion = the road width on the banked up portion × the vertical height from road level to the foot of the embankment divided by 2. The vertical height can be found with a slope template.

(B) *Two-sided Cuttings and Embankments.*

24. For an important road or tramway on fairly level ground, when it is important to get an even gradient, and to avoid switchbacks, it is necessary to take levels and to plot a longitudinal section of the actual ground level and the formation level (*i.e.*, the level of the proposed road). Pegs are put in at and levels taken to all points where the slope of the ground changes materially. A suitable scale for the plotting of the section is 100 ft. = 1 inch for the horizontal scale, and 10 ft. = 1 inch for the vertical scale. From the plate the necessary height of embankments and depth of cuttings are read off, and the necessary sectional areas carefully measured. Methods of measuring the cross section by plotting on squared paper are dealt with in the Forest Mensuration Manual, pages 59 and 60.

25. For ordinary forest roads simpler, but sufficiently accurate methods can be employed. When there is no cross slope from side to side, all that is required is to know the depth or height of cutting or embankment. The sectional area then = width of road *plus* horizontal width of one side slope multiplied by the height or depth of embankment or cutting at the centre. The horizontal width of the side slope = vertical height or depth divided by the inclination of the slope, *e.g.*, with a slope of 3 in 1 and depth of 6 ft., horizontal width $= \frac{6}{3} = 2$ ft. or with slope of 1 in $1\frac{1}{2}$ and depth of 6 ft. $= \frac{6}{1} \times \frac{3}{2} = 9$ ft. Where there is a cross slope it is necessary to find the height or depth of embankment or cutting at each side of the road as well as at the centre. The approximate average height or depth is then equal to that at one side *plus* that at the other side *plus* twice that at the centre divided by 4. When this is found the same formula can be used.

26. The necessary depth or height of cuttings or embankments can be found without plotting a longitudinal section as follows:—For a cutting set the level or clinometer at the required gradient of the finished road, and put it on the grade peg at the beginning of the cutting. Put the sight vane on the surface of the ground above the cutting and in the middle line of the road (or in the line of the edge of the road as the case may be). The distance between the point where the line of sight cuts the sight vane and the cross piece on the sight vane is the required depth of cutting. If the cutting goes deeper than the height of the sight vane, two or more successive readings may be necessary. To find the point where the road emerges from the cutting proceed as described below for embankments.

For an embankment the sight vane should be raised up until the line of sight cuts the cross piece, and the distance from the bottom of the sight vane to the ground is the required height of embankment.

Where the depth of cutting or height of embankment changes rapidly or is irregular, cross sections should be taken at close intervals, say, about 10 ft. or closer on very steep ground, but where they are fairly uniform and not very great, the intervals may be increased.

Where there is a cross slope the depth or height must be taken at the middle and at both sides to obtain the average, as already explained.

27. *Rates of payment for earthwork.*—A rate is fixed per 1,000 c. ft. (occasionally per 100 c. ft.). This rate may vary for different reasons, *e.g.* :—

(1) Kind of soil or rock—especially hard ground means a higher rate.

(2) A lead of more than 50 ft. or a lift of more than 5 ft. means a higher rate.

28. *Surface dressing.*—When the cutting or embanking is less than 1 ft. It includes all necessary digging and levelling of the road surface and = " S. D." in the form for details of measurements.

29. (3) *Clearing the roadway.*—(1) Jungle clearing includes felling and uprooting all trees under 12 inches diameter and clearing all undergrowth. Generally the rate for each mile is estimated and entered in the abstract of cost.

(2) Uprooting trees over 12 inches diameter and bamboo clumps. An average rate per tree or clump should be fixed to include removal of all timber and roots to a distance of 25 ft. from the centre of the road track. When actual work is done payment is often made per running foot of girth.

30. (4) *Miscellaneous points connected with the Estimate.*—The *gradient* is shown in degrees or horizontal equivalent according to the instrument used.

Forward bearing is not required except for level country where the alignment has been made with prismatic compass.

In the *remarks column* make notes of the nature of cutting, triangular (△) or two-sided ◻), with necessary back slopes, and kind of earth, whether particularly hard or rock requiring blasting, etc. Also note bridges and culverts with the span, and species of tree over 12 inches diameter to be removed, if marketable. A separate list of trees by diameter classes and species may, of course, be necessary for auction purposes.

Retaining and breast walls are not often necessary on forest roads, but when they have to be made, a note should be made in the remarks column, and separate volume calculations made and entered in an extra column in the abstract of cost.

The *Report and Specification* will be much on the same principles as for a building.

A *map* on a scale of, say, 4 inches = 1 mile should be made showing the main features of the country with the proposed road in red or other suitable colour.

A longitudinal section is only necessary for large and important roads.

5. Forest Road Construction.

A. *Organisation of Labour and Tools.*

31. If coolies cannot come from villages every day, make proper arrangements for a camp with good water supply near the work.

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Work should be done by contract or piece work rather than on daily labour, as less supervision is required, and the coolies work better. Before arranging to start work make sure that the necessary tools are available, *e.g.*, hoes, pickaxes, crowbars, baskets, etc. (*See* Lloyd's Engineering pages 93 to 96).

Boning staves are useful for checking the gradient of the road during construction—they consist of 3 staves or rods of equal length about 4½ ft. to 5 ft. long with horizontal crosspieces 2 ft. long at the top. Two are put on adjacent grade pegs and the third in between. When the cross pieces of all 3 are in line, then the intermediate one is at the correct level. (*See* Lloyd's Engineering plates pages 82 and 98.) This is much quicker than using levelling instruments.

B. *Method of Construction.*

32. (1) *General.*—Construction should generally begin as soon as possible after the rains, when the earth is soft and digging is easier, and the road surface can be consolidated more easily. No pegs must be removed, the ground for 1 ft. round each peg being left untouched till the work is completed and measured up for payment. This does not apply where embankments or deep cuttings have to be made.

33. (2) *Clearing the Roadway.*—This must be done well in advance of the earthwork. All trees, shrubs, and undergrowth are cleared roots and all. When there is sufficient depth of earth cutting to be done, shallow rooted trees may be cut high up and the stump extracted afterwards when the earth work is carried out. Otherwise all trees should be felled with roots. Old dry stumps may sometimes be burnt out. Large stumps may often be split with iron wedges. No roots, stumps, or boulders should be left in the roadway.

34. (3) *Roadside Clearing.*—Trees and undergrowth are under certain circumstances cleared for a certain width on each side of the roadway. In hilly country this is generally not done, as they prevent erosion. Only overhanging trees, or those on the upper side of the road likely to fall should be removed. In more level country complete clearing is sometimes done for a width of 10 to 15 ft. on each side, if it is an advantage to let in sun and air to dry the road. This should not be done in very dry areas, or in sandy places. Clearing should be done above deep 2-sided cuttings.

Clearing may also be necessary regardless of the above circumstances if a road is combined with a fireline.

35. (4) *Completion of the Road Surface.*—(a) *In level country*—Nothing remains to be done in the case of an earth road but Surface dressing, *i.e.*, levelling off uneven parts and filling hollows with stone or well-rammed earth.

36. (b) *In uneven and hilly country.*—Cuttings or embankments have to be made along considerable lengths of road.

Triangular cuttings have to be made where the road goes round hillsides. The full width of the road is usually cut out. Any gain in width resulting from excavated earth is not taken into account, as it will soon be washed away by rain if not held up by retaining walls, which would normally be much more expensive than the extra excavation. If, however, excavation has to be made in hard stony or rocky ground, and retaining walls can easily be built of local stone, it may be cheaper to cut out only part of the road width and use the excavated material to build up the remaining portion, keeping it in position with a retaining wall. This may also be necessary in order to get the necessary width of road round sharp curves or hairpin bends. Wherever the full width is cut out, retaining walls are not necessary except on particularly steep or unstable slopes.

All excavated material must be levelled off and not banked up above the road surface, as this would prevent water draining off. Cutting must never be done below the required road surface level, as filled up hollows are never as hard as the original ground surface.

37. *Two-sided cuttings.*—Have often to be made through ridges, spurs, etc., to keep the road at the proper gradient or to save long detours. The road should never be level in such places. It must have a gradient of at least 1 in 60 to ensure drainage—either a steady slope throughout, or a slope down from the centre to each end. The width of the road through 2-sided cuttings must be increased to allow for 12 or 18 inches wide drains at each side.

38. *Embankments.*—Are necessary either to cross dips at the required gradient, or to raise the road level above floods in low-lying ground. It is very important to provide sufficient waterway through embankments by means of culverts and bridges for all intercepted water. The road surface should be at least 2 ft. above highest flood level.

Before constructing an embankment lay out its profile at short intervals by erecting bamboos or wooden stakes in pairs the width of the top of the embankment apart, and up to the required height. Stretch cord across the tops of each pair, and peg it down at the sides at the proposed foot of the embankment, the cord thus showing the exact shape of the finished embankment.

Settlement of earth must be allowed for. For ordinary earth rammed allow $\frac{1}{6}$th the height (2 inches per foot), for unrammed earth $\frac{1}{3}$rd the height, and for gravel $\frac{1}{12}$th the height. Also allow for erosion and contraction at the sides, *e.g.*, for a 12 ft. road lay out the embankment 14 ft. wide.

For payment for earthwork used on embankments measurements are made in the borrow pits from which the earth is dug. If the embankment itself is measured after construction and before settlement the measurements will be much greater.

Materials for embankments must generally be what is near at hand. The choice is therefore limited; but if possible avoid heavy clay or soil with vegetable mould and rubbish in it. Gravel or shingle is good. During construction all lumps of earth must be broken up and well rammed. If on a hillside cut out the original surface in steps to help binding and prevent the embankment from slipping. On marshy ground make cross drains at frequent intervals under the embankment, making small culverts, or as a more temporary measure trenches filled with rammed brushwood; also make longitudinal drains along the sides. If the ground is soft, make a foundation of large boulders if available—otherwise several layers of brushwood or poles, the top layer being always across and not parallel to the roadway.

When complete keep traffic off the earthwork till it has settled; for one year for ordinary earth, and less for gravel, sand, or stone.

39. *Borrow pits*, from which the earth for embankments is dug, should never be less than 6 ft. from the foot of the embankment. They must be broad and shallow, not more than 3 ft. deep, and with sides vertical or in 1 ft. steps. Mark out pits with sides of 10 ft., or multiples of 10 to facilitate measuring. Witnesses or pillars of earth are left at intervals up to the original surface until the measurements are made. The sites of witnesses are selected beforehand and marked with pegs. Witnesses must be removed after measurement to prevent coolies claiming payment a second time. Borrow pits are sometimes made in the form of longitudinal

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drains, but if the ground slopes considerably or is unstable, make them in a series of separate pits not more than 100 ft. long to avoid the formation of streams and erosion. Whenever possible drain borrow pits into watercourses to prevent the collection of stagnant water.

40. *Slope of banks in cuttings and embankments.*—The slope at which soil will stand naturally after being thrown down freely and loosely and left exposed for some time is called its natural slope or angle of repose. This varies with the type of soil, and often with the amount of moisture in it:—*e.g.*, for damp but well-drained clay it is 1 in 1, but for very wet clay it is 1 in 3 to 1 in 4. For ordinary soils it generally varies from 1 in 1½ to 1 in 2.

The slopes generally used for embankments correspond fairly closely to the angle of repose, being in ordinary earth 1 in 1½, or for especially high embankments 1 in 2.

The sides of cuttings, being natural solid earth, may be made steeper. In certain cases, *e.g.*, in temporary roads or in cuttings of only a few feet; the sides may be left vertical if they will stand. Normally some slope must be given, varying from 3 in 1 to 1 in 2 according to the nature of the soil. Slopes in clay should be gentle, say 1 in 1½ or 1 in 2, as most clay, however hard to start with, soon disintegrates when exposed to the weather. In average soil 1 in 1 is a usual slope. 1½ in 1 or even 2 in 1 may sometimes be used in particularly firm ground.

41. (5) *Retaining and Breast Walls.*—Retaining walls are built at the outer edge of the road, *e.g.*, for bridge abutments or other places where it is necessary to hold up the earth below the road at a steeper slope than it will stand by itself. For ordinary forest roads they are rarely necessary apart from bridge abutments, except in hilly country where the slope is very steep and the soil unstable.

Breast walls are built to support the hillside above a road where it is so steep or unstable that it would otherwise slip down on to the road.

Retaining and breast walls, where stone is available, are generally built of random rubble, either coursed or not. They are generally of dry rubble, unless special strength is required. Dry stone walls can be built up to about 12 ft. If higher than 12 ft., the upper 12 ft. may be dry and the rest with lime mortar; or bands of masonry in lime mortar about 1 ft. thick may be made

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at intervals of not more than 6 ft. If lime mortar is used, weep holes, or small openings 2 to 3 inches square, must be made for drainage every 6 ft. vertically and horizontally starting at 1 ft. from the ground. They should slope slightly downwards from back to front, and their inlets be surrounded with loose stones. Foundations must be on the original ground and not on made earth. The foundation layer should be of the largest stones available.

If special strength is necessary make the foundation layer of masonry in lime mortar or with 2 ft. of concrete. A safe rule for the depth of wall below ground level is 1 ft., *plus* $\frac{1}{10}$th the height of wall, *e.g.*, a wall 10 ft. above ground should have its foundations 2 ft. down. The base of the wall must be at right angles to the front face. The top may be only 18 inches wide for walls up to 4 ft. height, and must be 2 ft. wide for heights above this. It is made horizontal as a rule, though for breast walls may be at right angles to the front face. The slope or batter given to the face of the wall is generally 3 in 1 or 4 in 1 for retaining walls, and for breast walls it varies from 2 in 1 to 6 in 1 according to the slope of the ground and the design of wall used. The back of the wall is usually vertical, though breast walls are often given a back slope of 3 in 1. With the top width fixed, the thickness at the base depends on the height and the slope of the face and back.

The back of the wall should be left rough, and projecting stones are desirable. In the construction of the wall stones should be laid roughly in courses even if proper courses are not made, and the base of each course should be at right angles to the face batter. Through headers should be laid at intervals of 5 ft. (See diagram in Lloyd's Engineering page 105.)

The backing of the wall should be of small stones or gravel, etc., and not of ordinary earth. Where a retaining wall is used to support a road crossing a small ravine, the ends of the wall should be stepped into the banks on each side. (*See* diagram in Lloyd's Engineering, page 105.) Retaining walls are sometimes made with the front face vertical, but in steps back from the base, the steps being at about 3 to 6 ft. intervals. This method is not so good, but is simpler in construction and useful where masons are not very skilful.

42. When calculating cubical contents of walls in a road estimate it is useful to have tables giving the area in sq. ft. for a

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given vertical height for the walls of the section to be used. The following tables give this for walls as given in the diagrams:—

Retaining Wall.		Breast Wall.	
Vertical Height ft.	Sectional area in Sq. ft.	Vertical Height.	Sectional area in Sq. ft.
3	9	3	7·6
3½	10·7	3½	9
4	12·5	4	10·4
4½	14·4	4½	12
5	16·4	5	13·5
5½	18·5	5½	15
6	20·6	6	16·8
6½	22·9	6½	18·5
7	25·3	7	20·2
7½	27·7	7½	22
8	30·3	8	23·8
8½	32·9	8½	25·7
9	35·6	9	27·7
9½	38·5	9½	29·6
10	41·4	10	31·7
10½	44·4	10½	33·7
11	47·5	11	35·9
11½	50·7	11½	38
12	54	12	40·3
12½	57·3	12½	42·5
13	60·8	13	44·8
13½	64·4	13½	47·2
14	68	14	49·6
14½	71·8	14½	52
15	75·6	15	54·5

43. (6) *Guard Posts.*—Sometimes called wheel-guards. Timber posts or stone pillars placed on the inside of sharp curves and on bridge approaches; also to protect side drains, and sometimes on the outside of sharp curves in hill roads. Stone pillars are preferable, but timber posts may be used. They should be about 2½ ft. above ground and sloping slightly outwards away from the road.

44. (7) *Drainage.*—(a) *General.*—Very important, especially for earth roads, which are damaged more by rain than by traffic. It is essential to minimise the erosion of the road surface by rain, and to prevent water lying on the road and softening it too much.

There are various methods of ensuring good drainage:—

(*i*) Good alignment on naturally well-drained ground.

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(*ii*) Suitable sloping of the road surface to prevent water lying on it, or running too far down it.

(*iii*) Construction of drainage channels to divert water from the road, combined with sufficient bridges, culverts, or Irish bridges to lead the water across the road where necessary.

45. (b) *Surface Drainage by Sloping the road Surface.*—In level country make a camber, the centre of the road being higher than the sides, the slope to each side for earth roads being about 1 in 24, *i.e.*, a 12 ft. road will be 3 inches higher in the centre than at the sides. For metalled roads the slope is generally slightly less, varying from 1 in 24 to 1 in 40.

In hilly country three methods can be employed:—an outward slope, an inward slope, or a camber. Each method has advantages and disadvantages, and opinions differ as to which is best.

With an outward slope the surface water from the hillside above flows straight across the road, and when rainfall is very heavy, or the soil unstable, erosion of the road surface is liable to be bad. But side drains on the inside and culverts and scuppers to carry the water from them across the road are unnecessary, and construction is therefore quicker and cheaper.

With an inward slope surface water from above the road is collected in the side drain and taken across under the road by culverts at intervals. Thus erosion is prevented, but construction is slower and more expensive, and extra labour is required for keeping the drains and culverts from getting choked up. An extra expense is that the road must be made at least 12 inches wider to allow for the side drain.

A cambered road has the same advantages and disadvantages as one with an inward slope, with the extra advantage that rain water falling directly on the road surface can only run over half instead of the whole road width, and thus danger of erosion is slightly lessened.

Many engineers nowadays advocate a camber both for hill roads and bridle paths, but for unmetalled forest cart roads and bridle paths an outward slope is probably best, being simpler and cheaper to make and maintain. The outward slope should be about 1 in 24, *i.e.*, the inside of a 12 ft. cart road is 6 inches higher than the outside. If the road has to be cut out of rock, the rock surface itself should be given an inward slope of 1 in 10 to prevent the covering of stones and earth from slipping off.

N.B.—For motor roads either in level or hilly country the road surface must be banked round curves, *i.e.*, the road at the outside of the curve must be higher than at the inside, the cross slope being, *e.g.*, 1 in 10 for curves of 50 ft. radius, and 1 in 20 for curves of 100 ft. radius. Banking is necessary not for drainage, but to enable fast moving vehicles to go round the curve more easily.

46. (c) *Side drains.*—In the plains drains on both sides of the road are advisable, though not always absolutely necessary. In hilly country, when the road has a camber or an inward slope, drains along the inside of the road are necessary. Drains should be wide and shallow, because deep narrow drains are more likely to get blocked up, and if made of earth the sides will more easily fall in. An earth drain of average size may be 9 inches deep, 2 ft. wide at the top, and 9 inches wide at the bottom. The best gradient is 1 in 120. If the gradient has to be much steeper, the average slope can be decreased by making steps at intervals with blocks of stone or timber, or as is normally done in hilly country, the drain should be lined with stone. There are many types of drains.

Drainage of 2—sided cuttings is particularly important. Water from outside must be diverted away, and a catch-water drain dug above the actual cutting, as well as side drains on both sides of the road through the cutting, the latter being protected by guard posts.

47. (d) *Irish Bridges.*—Paved dips in the road to carry water across from inside drains or from small streams which are only occasionally flooded. They are generally called scuppers when the span is up to 20 ft., and causeways if the span is more than 20 ft. They serve the same purpose as bridges and culverts, but are almost always much cheaper, and are thus often used where the water is not permanent, and floods do not last very long. Paving is done with stones, concrete, or reinforced concrete. In forest roads they are generally only made where good stone is available, stones of about 12 to 18 inches long, 6 to 9 inches deep, and 4 to 6 inches broad being suitable. No mortar is necessary if they are well-shaped and fitted. Lay the stones on edge with their length at right angles to the line of the road. The paved dip must be wide enough to take the water and shallow enough to prevent carts bumping too much. The downstream end of the dip must be protected with a drop wall built down well below the stream bed, and an apron along the foot of this wall is often necessary. A short drop wall may also be advisable on the upstream side to prevent

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scour undermining the paving of the dip. In the case of a stream the cross slope of the dip should if possible be the same as the slope of the stream bed, but in the hills this is seldom possible. It may be necessary to revet the banks of the stream for a short way above the road to prevent floods cutting into the road on each side of the dip.

48. On hill roads, and especially bridle paths, with an outward slope, small surface drains are often made across the road to prevent the water running too far down the length of the road and causing erosion. They can be made with poles (generally only temporary during the rains—See Lloyd's Engineering pages 109 and 111) or of stone. They should be made obliquely across the road, slanting outwards in the direction of the slope.

49. (8) *Road Surfaces.*—(a) *Earth.*—The natural surface is generally good enough, but improvement of the surface is sometimes necessary. Excess of sand or excess of clay are bad, the sand when dry and the clay when wet. To improve a very sandy surface take steps to conserve all moisture and to make the surface firmer and more resistant for wheels. For temporary improvement in dry weather put down a layer of grass, reeds, straw or other similar material. In very sandy river beds jhao (tamarix) or long grass can be tied in bundles of 6 inches diameter and placed across a trench dug the width of the road and about 12 inches deep. If clay is available, ram a good layer of clay over the top, and keep a thin layer of loose grass over the clay. For more permanent improvement of an ordinary rather sandy road mix clay with the sand. A more expensive way of improving very sandy roads for motors is to lay planks in the wheel tracks. Use 6 ft. to 8 ft. lengths with cross sleepers, the width for each wheel track being 2 ft.

N.B.—Sandy roads do not require surface drainage, and should not be given a camber.

Roads containing much clay can be improved by a dressing of sand or gravel. A layer of 4 to 6 inches of sand should be put on each year when the clay is still soft till the surface is satisfactory. If gravel is available, it is better than sand, but more expensive, as it needs ramming.

Where roads cross marshy places, corduroying may be used. Place poles of 5 to 10 inches diameter closely together across the road and cover with grass or branches and a layer of earth on top.

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The poles should be 16 ft. long for a 12 ft. road, and should be held down by longitudinal ribbands at each side. If necessary, a foundation layer of longitudinal logs may be placed under the cross poles.

50. (b) *Metalling.*—This is not often done on forest roads owing to the expense. Wherever it is possible, it is a great advantage if the amount of traffic is sufficient; as by reducing surface friction and improving drainage, it allows carting to be done all the year round and enables heavier loads to be carried.

In many parts of the plains kankar is used. It should be heavy and hard and dark in colour when broken. Soft white kankar which powders easily is no use. Where other stone is available it must be hard enough not to break into powder easily, but not too hard like flint, so that it will not consolidate properly. Sandstone is generally too soft. A mixture of hard and soft stones should never be used. The stone should be broken to an average size of about $2\frac{1}{2}$ inches. The earth surface, or 'sub-grade' under the metalling must be well rammed, and given the same camber as the finished road is to have. Any embankment to be metalled must be left for one rainy season to consolidate. On embankments or other soft places a foundation layer of large soling must be laid—stones 9 to 12 inches diameter. This is not necessary on ordinary ground. Two $4\frac{1}{2}$ inch layers of ordinary metal are generally laid, and they should consolidate to about 3 inches each. The first layer is rolled dry, rolling being better than ramming. The top layer must be kept wet during rolling, and when thoroughly consolidated a $\frac{1}{2}$ inch thick top dressing or binding is rolled in lightly, being generally of bajri; bajri of limestone is better than that of sand. This binding should never be added till the metal is thoroughly consolidated. Binding is not generally necessary on kankar. The earth backing or 'patris' at the sides of the metalling should be well rammed, and should slope outwards in continuation of the slope of the road surface.

For earth motor roads small patches of metalling are often essential where cart tracks cross them. This avoids deep ruts across the motor road. Metalling should be laid on the above principles, and will probably have to be rammed instead of rolled.

C. *Road Maintenance.*

51. (1) *Earth Roads.*—These require constant attention. Frequent small repairs before the surface gets too bad will save

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much subsequent expense. Drains must be repaired before the rains start, and kept continually in repair during the rains. Earth roads in the forest in the plains are not generally used during the rains, and care should be taken to prevent water running down slopes and eroding the surface. This can often be prevented by making small temporary drainage channels diagonally across the road near the top of a slope and at intervals down it. This is best done by small raised 'bandhs'. Annual repairs should be done as soon as possible after the end of the rains while the earth is still soft and in a condition to consolidate properly. Unnecessary scraping of the surface should be avoided. In level country earth should never be scraped from the road and thrown to the sides, as this destroys the camber and prevents proper drainage. It is much better to throw earth cleaned out of drains into ruts and hollows and onto the centre of the road, so that the camber is maintained. When filling up ruts and hollows always loosen the surrounding road surface, so that the new earth will bind with the old.

A road drag as described in Lloyd's Engineering pages 119 to 121 is useful under certain circumstances for repairing earth road surfaces.

When repairing earth motor roads after the rains, it is unnecessary always to scrape off all grass and other growth, if it is reasonably short. It often helps to bind the surface and keep it hard, especially where the soil is at all sandy.

52. (2) *Metalled Roads.*—Repairs may be just patching of small holes or ruts, or complete resurfacing. It is very important to fill up all holes and ruts before they get bad. The new metal is put in generally down to a depth of 3 inches, and should be well rammed with the addition of water until level with the old road surface. For complete resurfacing there are two methods:—

In the first a 4½ inch layer may be put on over the top of the old road. In this case any hollows should be patched first, and the whole surface is then very lightly picked over, and the new metal laid on top as for a new road. Before this is done a wall 8 inches wide and 6 inches high of well-puddled clay should be placed along each edge of the metalling to prevent the new metalling spreading during consolidation.

The other method is to use only 3 inches of new metal. In this case the old surface is dug up to about 2 inches depth, and the loosened material sorted out to separate from the rest all material,

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which is fit to use again and can be mixed with the new metal. The remainder—mostly earth and small stones—should be removed. It is not necessary to repair the old road surface in this case, as it will be dug up. The first method is probably the best. In either case consolidation with plenty of watering is done in the same way as for the top layer of a new road.

In all repairs it is important to use the same kind of metal as was used for the original surface, so that the two will combine properly together. The junction between the repaired and unrepaired sections of road must also be made level, as a sudden change of level is very bad for fast traffic.

VIII. BRIDGES.

1. TYPES OF BRIDGES.

A. *Classification.*

1. (1) *Floating or Fixed.*—Most bridges are fixed. Floating bridges are made of boats or pontoons anchored to the banks and to the bed of the stream and covered with girders and decking. They are generally temporary and taken up in the rains. They are often used across large rivers in the plains, when a fixed permanent bridge is not considered advisable.

(2) *Temporary or Permanent.*—Temporary bridges are used in places where they are only required for a short time; *e.g.*, until funds are available to build a permanent one; or for export of timber across a stream from a particular felling area for one or a few seasons only; or where it is impossible or not worth while to make a permanent one, *e.g.*, across a stream which is nearly dry in the working season and flooded in the rains.

(3) Of wood, brick, stone, concrete, steel, and rope or wire cables. Wooden bridges are generally made only in or near hills or forests, where wood is cheap and plentiful. Forest road bridges are nearly all of timber, owing to good timber being easily obtainable. They are not really permanent, though if well made and looked after, they may last 20 or even 30 years or more. Elsewhere bridges are generally either entirely of masonry with arches, or with masonry abutments and piers and steels girders or trusses, or of reinforced concrete.

Rope or wire cable suspension bridges are generally confined to the hills.

(4) Of single span or bay, or of several bays with intermediate piers.

B. *Choice of Type.*

2. The type of bridge used depends on the following:—

(1) The nature of the stream or other obstacle to be crossed; *e.g.*, the depth below road, rapidity of current, whether liable to heavy floods or not, etc.

(2) The natural foundations; whether intermediate piers can be made or not.

(3) The span, *i.e.*, the distance to be crossed.

(4) The kind of traffic for which it is required; heavy or light, temporary or permanent, etc.

(5) The materials available for construction; large sized timber of suitable strength, etc.

C. *Details of factors influencing choice of type.*

3. Timber bridges, such as will probably be built in the forest, will be considered except where otherwise stated.

4. (1) *Single Bay Bridges.*—The simplest form of bridge is a single piece of timber stretched across and supported on either side of the stream. This is developed into the single bay girder bridge of several girders laid side by side at short intervals with a decking or superstructure for the roadway. The banks on either side are strengthened to form abutments, upon which the girders are supported, the abutments being of masonry or timber. The span that can be bridged with single girders depends on the size and quality of timber available and the kind of traffic which will use the bridge. The usual maximum span for cart road bridges is taken as 20 feet, but if sound timber of sufficient size and strength is used and special care is taken in construction, bridges upto 30 feet span can be made; *e.g.*, in Burma with *Xylia dolabriformis*, or in the Himalaya with deodar. For foot and mule traffic in the hills a span up to 50 feet or exceptionally 60 feet is possible.

5. When the span is too great for single girders, various methods of construction can be employed. It may be necessary or desirable to have a single bay bridge because intermediate piers are impossible owing to the depth of the gap (as often happens in the hills); or because there are no suitable foundation for piers; or owing to the danger of piers obstructing the waterway too much if the stream is liable to high floods which bring down uprooted trees, etc.; or owing to the danger of piers being washed away if the current of the stream is too swift. In this case a strutted or trussed girder bridge, or a cantilever or a suspension bridge can be made. Strutted girder bridges with struts under the girders can be used up to spans of 45 feet. Trussed girders with trusses above the girders can be used up to spans of 60 feet or even more. Struts can also be used for a bridge under 20 feet span if timber of suitable size for girders of the required length is not available. Timber trusses for large spans are expensive and difficult to make, and owing to the large number of joints usually decay rapidly. For permanent bridges of large span steel trusses on masonry abutments are therefore preferable, but such bridges need skilled engineers for designing and construction and will not be dealt with here.

6. Cantilever bridges consist of layers of logs built up one above the other from both banks, each layer projecting out further than the one below until a gap of 15 or 20 feet remains, which is then bridged by single girders. These bridges are commonly used in the hills for foot passengers and animals. They can be made up to 120 feet span or occasionally even more.

7. Suspension bridges are also generally used only in the hills. Rough ones can be made of rope, but wire cables are generally used. The cables are suspended from uprights on each bank and are firmly anchored in the ground behind. The roadway is built across between the cables. These bridges are especially useful for large spans in out of the way places in the hills where transport of heavy materials is difficult. They can be made for spans up to 300 feet or even more. Large and elaborate ones can be made for heavy traffic, but in the forests they are generally made only for foot passengers and laden coolies or animals.

Of the above single bay bridges, cantilever and suspension bridges are generally confined to the hills, where they are only required for light traffic. Girder bridges are the usual type in the plains but may also be built in the hills if suitable timber is available, especially for short spans and where required for heavy traffic.

8. (2) *Bridges of several bays with intermediate piers.*—When a bridge must be over 20 feet span and there is no special reason for having a single bay bridge, it should be divided by piers into two or more bays. This is the usual method in the plains. In case of need, as already shown, single bay girder bridges can be made up to 60 feet or more if the girders are strutted or trussed, and it may sometimes be better to use a single bay strutted girder bridge for spans of from 20 to about 30 feet, even though there is a suitable foundation for piers. If the span is greater, it is nearly always more economical to use simple girders and intermediate piers. The bridge will then normally consist of 2 or more equal bays; *e.g.*, a 45 feet bridge will have 2 piers dividing it into 3 bays of 15 feet. But if the stream bed is deep and narrow and floods are likely to bring down much debris, it may be better to have a larger bay in the middle and two smaller ones at each side;

e.g., one of 20 feet and two of $12\frac{1}{2}$ feet, or the centre one may be strutted and made even larger.

9. Special cases may arise where a stream is subject to heavy floods which may bring down uprooted trees, etc., but is too wide, *e.g.*, say 180 feet, for a single bay bridge for heavy traffic. In this case a bridge with nine 20 feet bays, or even six 30 feet bays would not give enough room between piers. Thus four bays of 45 feet with strutted girders should do, or it might even be advisable to have three of 60 feet with trussed girders, or one central one of 60 feet and more smaller ones at the sides.

10. As a general rule, other considerations allowing it, the economic span for bays should be used, *i.e.*, the one of minimum cost. This is when the cost of one bay equals the cost of one pier. The cost of a bay in this calculation does not include decking, railings, metalling, or any other part of the cost which does not vary with the length of the bays.

Example for a bridge of 120 feet span:—

For 10 ft. bays . .	12 bays cost 40 × 12 = 480	Total	. 2,300
	13 piers „ 140 × 13 = 1,820		
For 20 ft. bays . .	6 bays cost 160 × 6 = 960	Total	. 2,080
	7 piers „ 160 × 7 = 1,120		
For 40 ft. bays . .	3 bays cost 640 × 3 = 1,920	Total	2,720
	4 piers „ 200 × 4 = 800		

Other factors which may favour larger bays rather than smaller ones are:—

(*a*) To get an equal waterway smaller bays require a greater total length of bridging, owing to the larger number of piers reducing the waterway in a given length, and thus a greater length is necessary to get a given waterway.

(*b*) By increasing the number of piers any difficulties met with in foundations are multiplied, and greater obstruction to the stream and consequently greater scour is caused.

2. Selection of Site.

11. The site is often determined by the position of the road, as the bridge must be in a fairly direct line with the main direction of the road, and long detours for a slightly better site are not generally worth while. If the road has not yet been laid out,

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bridge sites should be carefully chosen beforehand, and be made obligatory points for the road. In any case the following principles must be adhered to as far as possible when choosing the site. It must be in a fairly straight reach of the river and where the current is straight, and not at or near a sharp bend or near the junction of two streams, nor where the stream is likely to change its course. Erosion is greatest at bends. If the site has to be anywhere near a bend or large tributary, it should be upstream from them if possible; otherwise far enough below to be free from their disturbing effects on the current. The banks should if possible be fairly equal in height, approximately parallel, well defined, and well above flood level. High vertical banks generally indicate firm stable soil and permanence of the stream channel. A site where the span is narrowest is generally the best, especially in rocky hill streams, and for single bay bridges in general. But in ordinary streams in the plains if a sudden narrowing of the stream takes place, it means that the current becomes faster, and such places may be dangerous for a bridge with piers owing to the scouring action of the swift current; and it may be better to choose a site where the banks are a bit further apart, but are parallel for some distance up and down stream.

When piers have to be built choose a site which offers the best foundations. Firm foundations are essential. The depth of the foundations must be below erosion and scour caused by the greatest possible flood. Rock is the best foundation, though firm earth below the danger of scour is all right.

12. The bridge must cross the stream as nearly as possible at right-angles to the current to avoid having to build a skew bridge, and it must be easily accessible from both sides. To ensure this certain conditions must be fulfilled in laying out approaches, and should be remembered when choosing the site. For at least 10 feet at each end of the bridge, and for 20 feet or more if it is a cart road, the road must be level and in the same straight line as the bridge if possible, and there must be no sharp bends in the approaches. If approach roads cannot be laid out at right-angles to the abutment without too sharp bends, a skew bridge must be made. But it is difficult to construct, and can generally be avoided by careful selection of site. The gradient of approaches must be as gentle as possible, and must not exceed the maximum allowed for the particular road. Approaches must be well above the flood level of the stream.

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3. RIVER TRAINING.

13. This is rarely necessary if the site is properly chosen. If there is special danger of erosion of banks and abutments due to the stream tending to change its course, and the usual protection of wing walls and revetment walling is not enough, the stream must be trained. The banks must be strengthened, beginning a good way upstream, and the water led into the required channel by guide banks. The usual methods are stone and cribwork piers. A stream cannot be turned by direct opposition; it should be led into the required channels and no attempt should be made to force it. More details regarding river training will be given later on.

4. WATERWAY.

14. The waterway to be allowed through the bridge must be estimated. This is difficult, as the bridge is generally made in the dry season. Allowance must be made for the greatest flow of water that may pass during floods with something extra for emergencies. The site should be visited in the rains if possible; otherwise as soon as possible after the rains, and marks of floods on the bank and on trees and bushes should be looked for, and enquiries made from local villagers.

The total span of the bridge should not usually be less than the average distance between banks, so as not to restrict the natural waterway of the stream, which is generally a dangerous thing to do, especially if it subject to heavy floods. It may occasionally be necessary for wide and shallow streams. If the natural waterway is restricted a rise of water or afflux under the bridge will be caused, and the velocity of the water through the bridge will also be increased, and this will probably increase the scour and cause erosion in the bed of the stream and tend to undermine the piers and abutments.

In fixing the height of the bridge, apart from any afflux that may occur, it is safer to allow a certain clearance above the highest flood level (H. F. L.):—

(*a*) for ordinary streams at least 2 feet;

(*b*) for floating streams or in cases where large pieces of timber or floating trees and branches are brought down in floods:—at least 3 feet to prevent timber and debris striking and damaging the girders and collecting against the top of the bridge.

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15. The necessary total span and height of the bridge can generally be estimated for small bridges by careful inspection on the above lines at and near the proposed site. For large streams, and where the banks are not clearly defined it will be advisable to proceed as follows:—

Fix 3 places, one at the proposed site, and 2 others within a mile above and below where the banks are representative and if possible well-defined. At each place fix H. F. L. by flood marks or enquiry, or failing this by estimation after studying the drainage area above the site on the ground if possible, or from a map. If the drainage area is large, and in bare hilly country and the rainfall heavy, high floods are likely. If the country is level and covered with forest, floods will be less. Then plot on squared paper an accurate section of the stream bed at right-angles to the course of the stream at each of the 3 places. Measure the cross sections by stretching a tape or rope across the stream at H. F. L., and measure the depth at intervals of 5 or 10 feet with bamboo rods marked in feet and inches, or by other suitable means. Calculate the area in square feet contained between H. F. L. and the bed of the stream, and take the average of the three. This will give an idea of the amount of water likely to come down in the highest flood, and of the amount of waterway to be allowed at the bridge site. The abutments of the bridge will normally be at or close to the banks. Fix the position of the abutments tentatively, and then calculate the sectional area of waterway between abutments up to H. F. L., making the necessary deduction for piers, if any. If the resulting area is less than the average previously calculated, the abutments should if possible be moved further from each other so as to give the necessary amount of waterway. If this is impossible, then the bridge must be increased in height to allow for the afflux, and special precautions may be necessary to protect piers and abutments from scour.

16. The amount of afflux varies with the velocity of the stream and with the proportion between the amount of obstruction and the natural waterway of the stream:—*e.g.*, supposing the mean sectional area of the stream to H. F. L. is 2,000 square feet, and abutments and piers have to be so placed as to contract the natural waterway to 1,500 square feet. The obstruction is 500 or 25 per cent. If the mean velocity is 8 feet per second, the afflux will be a little less than 1 foot. The clearance to be allowed must therefore be increased by 1 foot. The mean velocity of most streams in the

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plains is not likely to be much more than 8 feet per second, or nearly $5\frac{1}{2}$ miles an hour. A rough way of calculating velocity is by timing floating objects over a given distance. This gives the surface velocity. The mean velocity is less than this, being approximately $\frac{4}{5}$th the surface velocity when the latter is less than 3 feet per second, and $\frac{9}{10}$th when it is greater than this. The afflux may be found from the following formula:—

$$\text{Afflux} = \left(\frac{V^2}{58{\cdot}6} + 0{\cdot}05\right)\left[\left(\frac{A}{a}\right)^2 - 1\right] \text{ in feet.}$$

Where V = mean velocity in feet per sec. previous to obstruction, *i.e.*, of the natural waterway.

A = sectional area of stream in square feet to H. F. L. unobstructed.

a = ditto allowing for the obstruction and under original water level at H. F. L., *i.e.*, neglecting afflux.

The following gives an idea of afflux in a few cases:—

V	Afflux in feet when obstruction compared with A is:—			
	$\frac{1}{10}$	$\frac{3}{10}$	$\frac{5}{10}$	$\frac{7}{10}$
2	0·03	0·12	0·35	1·20
4	0·07	0·34	0·97	3·28
5	0·11	0·51	1·49	5·02
6	0·15	0·69	1·99	6·72
10	0·41	1·82	5·27	17·76

17. It may be advisable sometimes to know what the increase in velocity due to the obstruction will be. An increase above a certain figure will be dangerous owing to excessive scour. The danger point depends on the nature of the stream bed and of the foundations for piers and abutments. Much less velocity is dangerous for a sandy bed than for a rocky one, and the velocity to be allowed also varies with the depth of the foundations and whether they are on firm ground or not.

The increase in velocity can be found by the formula:—

$$\text{Mean velocity of artificial waterway} = v = \frac{A}{a'} \times V.$$

A and V are the same as before.

a' is the sectional area of stream at obstruction including increment due to afflux.

e.g., suppose $A = 4{,}600$, $V = 3{\cdot}7$, mean depth $= 9$ feet, $a =$ sectional area through 3 openings each 50 feet wide $= 3 \times 50 \times 9 = 1{,}350$.

Obstruction therefore $= 3{,}250$ or $\frac{7}{10}$.

Afflux = approximately 3 feet.

Therefore $a' = 3 \times 50 \times (9 + 3) = 1800$.

Therefore $v = \frac{4600}{1800} \times 3{\cdot}7 = 9{\cdot}5$, which is too fast to be safe in a river with a sandy bed in the plains.

5. Details of Construction of Bridges.

A. *General.*

18. Timber bridges in the forest should be of as simple a design as possible, so that unskilled labour can erect them. The carpentry joints should be reduced to a minimum, as they collect moisture and are the first to decay. Unless a sawmill is handy, it is probably more economical to use round timber with sapwood trimmed off for girders and posts and piles and other heavy parts.

B. *Approaches.*

19. Several points connected with approaches have already been mentioned under selection of site. The following should also be noted:—If the road slopes down to the bridge, side drains must be made, and must be led off well short of abutments to prevent rain water rushing down and damaging them.

The road close to the end of the bridge for a distance of 2 to 4 feet is apt to sink, and it should be strengthened by thorough ramming and filling with metalling if available. Any large trees which will overshadow the bridge should be felled. A common fault when making small bridges in the plains over shallow waterways is to make them too high and to make insufficient embankment on each side, so that there is a sudden rise up to and a sudden drop down from the bridge. This should be avoided. Do not make the bridge higher than is really necessary, and always make the slope of approaches gradual.

C. *Simple Girder Bridges.*

20. These consist of 2 abutments with intermediate piers where necessary, capsill beams across the top of the abutments and piers, girders (*i.e.*, roadbearers) resting on the capsill beams, and deck planking laid across the girders.

21. (1) *Abutments.*—If stone is available they are often made of stone masonry, without mortar for small unimportant bridges, but generally with lime mortar. In this case capsill beams are laid along the top of the masonry, or the girders rest directly on large slabs of stone built into the top of the abutment wall. Wing walls generally go back diagonally from the abutments, though they may sometimes be made at right-angles to the abutments, specially on the down-stream side. Their length is normally 1½ times the height of the roadway above the bed of the stream. Rules for thickness, batter, etc., are the same as for retaining walls. It is better to make their foundations throughout their length at the same depth as those of the abutments, though in very compact soils or rock they may be stepped up, straight vertical joints being made between sections of different height to avoid cracking from unequal settlement.

22. Where stone is not available, specially made abutments are sometimes dispensed with, and timber ground plates or sills are laid on top of the bank to support the girders. This is generally unsatisfactory, as the banks are very likely to get eroded in floods, and the ground plate will then collapse. The weight of the bridge alone may also cause the bank to break down. The only cases where such sills may be used is for temporary bridges, and for small culverts, or if the banks are of rock or are very solid and stable. If used, they must be placed well behind the natural slope of the banks and kept in position by strong posts sunk well into the ground on the stream side. They should be of the largest sized timber available.

23. The usual way when stone is not available is to form abutments of posts sunk or driven below the bed of the stream. There are generally 2 to 4 main posts according to the width of the bridge. Three are enough for a bridge with a 10 to 12 feet wide roadway. These are fixed in a line parallel to the current of the stream. Two or more other posts support the wing walls, which go back diagonally from the main abutments.

In small streams and where foundations are firm enough, and there is no danger of them being exposed by scour, the main posts may be sunk 4 feet below the bed of the stream by digging a trench, and they should then be fixed to a bed plate of 12 × 5 inches timber by round tenons 2½ inches diameter, fitting into mortises on the bedplate, or by trenails (dowel pins). The bedplate should rest on rammed stone or similar hard foundation.

24. For larger streams, and where foundations are not firm enough for posts resting on bedplates, and in every case where the presence of water or loose wet sand or mud prevents excavation to 4 or 5 feet, the posts must be driven into the ground, and are then called piles. Round timber should be used for posts and piles. It should be carefully selected, and must be straight, sound, and free from large knots and shakes. It should have all the sapwood trimmed off, and the larger or lower end should be cut to a blunt chisel-shaped point. This is better than an ordinary fine round point, as it is less likely to break or glance to one side if it meets large stones or other obstacles. Piles sometimes have iron shoes or points fitted over their ends when to be driven in hard ground, but this is seldom necessary in ordinary soil. The top or head should be cut off square and level, and an iron ring 2 to 4 inches deep and ½ to 1 inch thick should generally be fitted over to prevent splitting. This may not be necessary for short piles for small bridges. Piles vary in size according to the size of the bridge and the depth to which they must be driven. For cart road bridges the mean diameter is generally between 10 and 14 inches. The necessary depth they must be driven may be only 5 to 6 feet for small piles, with a maximum depth of 10 feet in hard ground and 20 feet in soft ground for any bridge. It may often be necessary to drive a test pile to find the required depth.

25. *Pile driving.*—Small piles may be driven by two or more men using a heavy wooden rammer, and there are various other simple expedients. For larger piles proper pile driving machines must be used. There are many kinds, and rough ones can fairly easily be made. The main principles are that a heavy weight, generally of iron, called a monkey, is slung by a rope over a pulley fixed at the top of a vertical frame at the necessary height. The monkey is pulled up to the top either by hand or with a windlass (crab winch), and is then allowed to fall by its own weight on the pile head. There must also be some means of guiding the monkey straight onto the pile. The pile must be kept in position during driving by 3 or 4 guy ropes. The pile driving machine has to be supported on a platform, especially when long piles are being driven.

The weight of the monkey should if possible equal the weight of the pile. A heavy monkey dropped frequently from a comparatively small height is generally better than a light one raised higher and dropped at longer intervals. Piles should normally be driven into the ground until the penetration is only $\frac{1}{4}$ to $\frac{1}{2}$ inch per blow of the monkey. If driving is continued after this, and the monkey rebounds considerably, the pile may split or even break. To prevent contractors cutting off the tops of piles to avoid driving them to the proper depth, they should be indelibly marked at measured intervals from the point.

26. *Abutment revetments and anchoring.*—If suitable stone is available the abutments should be faced with large stones, the banks being suitably sloped. In this case wing piles are not necessary. In other cases timber revetments must be fixed behind the piles, made either of poles not less than 8 inches diameter at the butt end, or of planks. Poles should have the sapwood removed at any rate where they come in contact with each other and should fit close, having butt ends and small ends laid together alternately. Timber revetments should always be carried well down below the bed of the stream to prevent undermining, and the space behind should be filled with gravel or stones if available.

Posts on bedplates should always be anchored back to a firm anchorage post about 12 feet from the bank. Anchoring can be done with strong wire, but wooden ties are better. Short piles may not need anchoring, but it is always better to anchor them if they are more than 8 feet above ground. If the wing walls are long and have several wing piles, more than one anchor post may be necessary.

27. (2) *Piers.*—Piers should always be parallel to the main direction of the current and to the abutments and to each other.

Single rows of posts on bedplates may sometimes be used if the foundations are suitable, but generally it is necessary to drive piles. They should be braced by diagonal braces, and a horizontal ledger is usually placed at the foot of the braces. When the stream has a strong current, or heavy floods are usual, a side strut may be placed on the downstream side. Occasionally if much debris and uprooted trees are brought down in floods it may also be advisable to drive separate short protection piles one or two feet away on the upstream side. Piers should be of sufficient height to raise the centre of the bridge slightly, say $\frac{1}{60}$th the total span. This allows for settlement after erection, and a slight camber will probably remain, which is always an advantage.

28. *Other forms of piers.—Cribwork piers* may be used for dry ravines and other places where no great danger from floods and

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floating timber and debris is to be feared, and also for temporary bridges. The bed of the stream must be fairly firm. They are rectangular wooden frames made of a series of poles about 8 inches diameter, notched and spiked, or trenailed together, and filled with stones. The crib should have a rough tray of poles made across the bottom to prevent stones being washed out if it is undermined by the current. Its base should be sunk well into the bed of the stream. Cribs should not normally be used for heights of more than 8 feet. Their length from side to side of the bridge should be at least 1½ times the width of the roadway.

29. *Trestles* are sometimes used when the bed of the stream is rock or is very stable, and the flow of water not more than 5 miles an hour (7⅓ feet per second). They are specially useful for temporary bridges, as they can be erected and removed easily and quickly. They can be made of poles, notched and spiked or dogged together. They can also be lashed together with wire or rope as a more temporary measure. Stronger and more permanent forms are made of sawn timber properly framed together. The outer posts of all trestles should be at a slope of 6 in 1. The simplest form consists of 2 outer posts or legs, 2 horizontal cross posts (the transom at the top and ledger at the bottom), and 2 diagonals.

30. *Dry rubble piers* can sometimes be used when suitable stone is available, but only in depressions or streams down which very little water flows.

31. (3) *Capsill Beams.*—Capsills, sometimes called transoms, are horizontal beams fixed across the top of the abutments or piers, the chief object being to support the road girders and distribute their weight, but they also help to brace the top of the posts or piles together and keep them firmly in position. There are several methods of fixing them. Probably the best way is to use two capsills of equal size (about 9 × 5 inches), one on each side of the line of piles, bolted into notches cut to receive them, and a cleat is added beneath to strengthen the joint. The advantage of this is that the outer main piles can be continued up to form rail posts, only the centre pile or piles being cut off just above the capsills to allow the decking to be fixed.

32. Another method is to cut off all piles at the same level and fix one capsill across the top of them. This is easier and probably stronger to start with, but as the ends of the piles usually decay first, the capsill is liable to become loose and be displaced quicker. In the latter method the capsills can be kept in position by dowel

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pins or iron dogs, or have iron straps passing over them and bolted at both ends to the post.

33. A method which should never be employed is to cut a notch in the top of the pile, so that the capsill fits exactly into it. This hastens decay, and the outer projecting parts of the pile are very apt to decay and break, and then the capsill is left loose, and will be very liable to slip out of position.

34. (4) *Girders.*—Girders may be of round timber, and this is generally more economical than sawn timber, unless a sawmill is near to the site, or unless small-sized sawn timber and offcuts can be easily and profitably disposed of. Round girders must be very straight and have all sapwood trimmed off. One foot mean diameter of heartwood is sufficient for spans of 20 feet or even greater for cartroad bridges. For short spans smaller sizes can be used, though in Burma bridges down to 12 feet span have 1 foot diameter girders.

For sawn girders about 10 × 6 inches is generally enough for cart road bridges for the largest spans, with smaller sizes for short spans.

35. Normally 3 or 4 girders spaced at equal distances are used for cart road bridges, and 2 may be sufficient for light traffic. Girders should overlap the capsill beams by at least one foot, and in bridges with piers, where two or more lengths of girders are necessary, they should overlap each other on the piers. They should never be halved together provided available timber is long enough to overlap. Joints weaken the timber and cause early decay. If by any chance it is necessary to halve them, short pieces of timber called bolsters or corbels should be placed under the joints and across the top of the capsills to act as fish plates. If round girders are used, level off the top surface so that the decking bears equally on all of them. Where they rest on capsills keep them in position by wooden cleats or wedges, and where they overlap they may be bolted together.

36. If using sawn timber, and if beams of sufficient sectional area are not available, two beams may be bolted together one above the other with wooden keys to prevent one sliding over the other. The total depth of all the keys should be a little more than $1\frac{1}{3}$ the depth of the joined beams, and the total width twice their depth.

37. (5) *Decking.*—Planks are laid across the girders. The best size for wheeled traffic is 6 inches wide and 3 inches thick. For

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light traffic 1½ to 2 inches thick is enough. They are nailed or spiked to the girders. The best arrangement is to nail them only to the one or two centre girders, and to hold down the ends with two ribbands or wheel guards of 6 × 3 inch planking running along each side of the bridge and bolted through to the girders with ½ inch bolts. This allows for the expansion and contraction of the decking planks in their length, and prevents warping and loosening of spikes. Planks should be laid with ¼ inch gaps between to allow for expansion when wet without preventing rain water from draining through. For wheeled traffic, especially motors, a second layer of planking may be laid longitudinally at the sides only to take the wear of the traffic. Planking is apt to wear out quickly with heavy traffic, and thus this upper layer can be renewed easily without replacing the whole decking. A disadvantage is that it becomes more slippery for animals when wet than cross planking. Decking should never be covered with earth, as it holds moisture and causes the planks to rot quicker.

38. (6) *Railings.*—These consist of upright posts about 5 × 4 inches projecting about 4 feet above the decking and about 6 feet apart. The tops of posts should be pointed to throw off rain water and improve the appearance. Two rows of rails are fixed on the inside of the posts, the height of the top rail being about 3 feet 6 inches above the decking. They are generally of sawn timber, about 4 × 2 inches, and are spiked to the posts, which are notched to receive them. Plain wire can be used, but is not so satisfactory. Two decking planks adjoining each post are prolonged for 2 feet on both sides of the bridge to receive the post struts.

If the outer piles of abutments and piers are prolonged above the decking, they act as rail posts, and intermediate posts are fixed at the necessary intervals in between. This greatly strengthens the railings.

Rail posts are often just tenoned into the road planks, but are then never very firm. A better way is to place them so that they can be carried down through the decking and spiked firmly to the outside of the girders below. The rail posts in this case are made 5 feet long. They should also be notched 2 inches deep for the wheel-guards; this helps to keep the latter in position.

D. *Strutted Girder Bridges.*

39. For spans up to 45 feet.

Abutments, piers, capsill beams, decking, and railings are made as already described for simple girder bridges. The road girders

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are generally of sawn timber in pairs butted together in the centre of the bay, and supported underneath by a straining beam between two struts, the girders being bolted to the straining beam. The straining beam is $\frac{1}{3}$ the span, and the depth from the girders to the foot of the struts not less than $\frac{1}{6}$ the span. The lower end of the struts are supported on ledgers bolted to the abutment piles or pier piles. Ties are generally fixed between the girders and the centre of the struts, especially for larger spans. For extra strength to prevent lateral spreading the struts may be tied together horizontally across the bridge. The base of the struts should if possible be above H.F.L. The straining beam and struts and girders are generally all the same size, 8 × 4 inches being sufficient. The mitre joints connecting the struts to the straining beam are straight and made as nearly as possible at right angles to the direction of pressure. They are strengthened with iron straps about 3 feet long, 2 inches wide, and $\frac{1}{4}$ to $\frac{1}{2}$ inch thick.

If girders of round timber long enough to reach across the whole span are used, two light transoms or cross beams of the same length as the width of the bridge are fixed above the straining beams so as to join them all together. The girders then rest across the transoms. This arrangement must also be used if the struts are not placed immediately under the girders; *e.g.*, three lots of struts and straining beams to four girders.

E. *Trussed Girder Bridges.*

40. For spans of 45 to 60 feet, or for shorter spans if a strutted bridge of the required height will obstruct the waterway too much, and it is not desired to raise the height of the bridge.

The general principle is that two parallel trusses stretch along the outside of the bridge across the whole span, and decking is supported in the usual way on road girders which rest on transverse girders stretching across from the base of one truss to that of the other.

There are many forms of trusses. King post and Queen post trusses were often used in the past, but are not very satisfactory for forest bridges, as they need skilled carpenters to make the elaborate joints, and if thoroughly seasoned wood is not used, the joints will soon open out and give trouble.

41. When timber trusses have to be made, the Howe trussed girder design is probably the best. Each truss is composed of an upper and lower chord or boom connected by diagonal braces or struts of timber (under compression), and vertical tie rods of iron (under tension). The depth of the truss is usually $\frac{1}{6}$ to $\frac{1}{10}$ the span. The horizontal chords are each made of 3 rows of planks set on edge and bolted together to break joint. The timber struts are also made of 3 thicknesses of planks, and the iron ties are in pairs. The sets of planks forming the chords and struts are separated by packing pieces of the same thickness as the planks, and put in at all joints. The iron tie rods pass through these packing pieces, and thus the planks themselves are not weakened. The cross girders which support the road bearers are each made of 2 beams bolted together, and project alternately on each side so as to support the wind struts of the truss.

The bridge needs a temporary scaffolding built up from the stream bed across from one abutment to the other so that the trusses may be put together on it.

F. *Cantilever Bridges.*

42. The foundations of the cantilevers on the bank must be firm:—*e.g.*, rock or stones. If necessary dry rubble masonry may be built up round and over the buried ends, using as large blocks of stone as possible, especially at the base if it will be exposed to a swift current. Sawn timber beams may also be built into the masonry, especially immediately above and below the cantilevers.

The arms of the bridge which project out from either bank may each consist of a single layer of cantilevers, or of several one above the other. This depends on the span to be bridged and on the size of logs available.

43. The simplest form of bridge is for a footbridge with each arm formed of two logs:—*e.g.*, for a clear span of 42 ft. where straight chir logs 30 ft. long are available. Each arm is composed of two 30 ft. logs sloping slightly upwards and buried for 20 ft. of their length in boulders. Thus 10 ft. length will project over the stream. The top ends of the 2 logs are connected with a transom, on which the 2 horizontal road bearers rest, each 30 ft. long and with a clear span of about 26 ft. Cross planking about 3 ft. wide is laid on the road bearers, which are connected with the top of the abutments with planks or with poles and more cross planking.

44. It is usual to bury the first or lowest layer of logs of the arm for about $\frac{2}{3}$ their length, and they should be well weighted with stones on top. When the span is too great for single layers of cantilevers, other layers are built out above the first layer till the distance remaining to be spanned is short enough. Each layer projects beyond the layer below it between 5 and 12 ft., the top ends being connected with a transom on which the next layer rests. Intermediate transoms between the highest one and the abutment also strengthen the arm. The number of logs in each layer may be the same, but it greatly increases the strength if each layer consists of 1 or 2 more logs than the one above it. If the arm consists of several layers, it may be advisable to support the logs connecting the central road bearers and the top of the abutments with one or more supports resting on the top cantilevers. The logs forming the cantilevers should have their thick ends uppermost.

45. There are various ways of strengthening a cantilever bridge in order to increase the span, or to allow heavier traffic. The centre road bearers can be supported underneath with wooden struts and iron tie rods, or the whole bridge can be stiffened by wire ties, each pair of ties being supported on a pier on the bank and anchored behind as for a suspension bridge and fastened to the upper end of the top cantilever.

G. *Suspension Bridges.*

46. (1) *General Principles.*—Two cables, one on each side, hang in a curve across the gap to be bridged. They are supported over upright piers standing one on each abutment, and are kept firm by being anchored in the ground behind the abutments. Occasionally the roadway is carried directly on the cables themselves, but it is usually suspended by wire slings from the cables. The best material for the cables is wire rope, as it is the strongest and most durable and does not stretch. Other materials can, if necessary be used; *e.g.*, ordinary rope, canes (chiefly in the Eastern Himalaya), and even bamboo strips or twigs of certain trees.

47. (2) *Arrangement of the Cables.*—The *dip of the cables* at the centre of the span below the level of the top of the pier should normally be between $\frac{1}{10}$ and $\frac{1}{15}$ the span. The less the dip the stiffer the bridge and the less easily will the weight of the bridge tend to drag out the anchors, but the greater the tension on the cables. Something between the above ratios gives the best mean between these two conflicting forces. Although the further away the anchorages are from the piers the less easily will the anchors be dragged out, nevertheless they should if possible be fixed at such a distance from the piers that the cable will make equal angles on each side of it. In practice their position often depends on the nature and stability of the ground behind the piers, and if it is not possible to make the angles equal, then the piers, if of wooden posts, should be strutted, or guyed behind, to prevent overturning.

48. The *width of the two main cables* at the centre of the bridge will be approximately the same as the roadway. At the piers it should be considerably greater, and at the anchorages greater still. The greater the increase in width up to a certain point, the firmer will the anchorages be, and the less will the bridge be apt to sway. The increase in width at the piers should be not less than 3 ft. and may be up to 10 ft.

Examples:—

Span 146 ft. width between cables at centre 5 ft. at piers $13\frac{1}{2}$ ft.

Span 190 ft. width between cables at centre $4\frac{1}{2}$ ft. at piers $11\frac{1}{3}$ ft.

49. (3) *Anchorage.*—Solid rock, if hard and durable, is the best foundation, and it may be sufficient to bore holes 2 to $2\frac{1}{2}$ ft. deep in the rock and fix $2\frac{1}{2}$ to 3 inch diameter steel bars with ringed heads into the holes with cement, and fasten the cables to the rings. Stones may be built over the anchors to increase the strength, though it is generally better if they can be left exposed to facilitate subsequent inspection.

50. Another method is to fasten the cable to a large log 15 to 18 inches diameter resting on the rock, and to anchor the log with two rows of steel bars, one row in front of it and one row behind, the two rows being anchored together with wire. The cable is passed twice round the log and the free or running end twisted round the standing part and securely bound with wire. The steel bars must always be at right angles to the direction of the cable. The above dimensions of bars, etc., are sufficient for bridges up to 200 ft. span or slightly more.

51. If suitable rock is not available, other methods are necessary. One is similar to the previous ones. The cable is passed through the centre of a horizontal log embedded in sand and then wound several times round it, the end being treated as before, or it may have the strands separated and each fastened individually to the log. The horizontal log is kept in position by 3 inclined logs against it, each 7 ft. long and buried $5\frac{1}{2}$ ft. in the ground.

52. Another way is when the abutments of the bridge are built up with a wooden framing of crossed logs of about 12 inches

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diameter fastened with pegs, the interstices being filled with stone. The cables are turned several times round logs, the first log being buried beneath about 4 ft. of abutment, and the 2nd log being a little beyond and above it. A less elaborate way is simply to wind the cables round logs buried deeply in the ground and covered with a heap of stones.

53. (4) *Piers.*—These may be of masonry, but are generally formed of wooden supports, each cable passing over the top of a wooden post fixed firmly in the ground, the two posts being connected by cross bars at the top and bottom. The lower cross bar is often prolonged some distance beyond the standards on either side, and struts may be fixed to the standards to strengthen the whole structure further. The cable may be kept in position by cutting a notch in the top of the post for it to rest in, or a hole near the top of the post for it to pass through. In the first case the cross bar can be fixed over the top of the posts; or if the cross bar is below the top, then an iron strap should be bolted over the top to keep the cable from jumping out. A better method is to have a curved iron flange for the cable to rest on, and the cable is kept in position by an iron stirrup passing over the top and bolted to the post below.

54. (5) *Roadway.*—The wire slings which carry the roadway, are hung from the main cables at intervals of 5 to 10 ft. The length of each one must be carefully worked out, as they will get gradually shorter from the piers towards the centre of the bridge owing to the dip of the main cables. The roadway should also have a camber of $\frac{1}{60}$ the span, *i.e.*, in a span of 120 ft. the roadway in the middle of the bridge should be 2 ft. higher than at the piers. The lower ends of the slings are fastened to cross pieces or transoms, which support the stringers or roadbearers, longitudinal beams on which the road planks are nailed. A good way to fasten the cross pieces to the slings is to use a screw bolt ending in a ring. The sling is passed through the ring and turned up, and the individual strands of the end opened out and wound round the sling and bound with wire. Roadbearers should be joined over the transoms. It is better to make them overlapping, though they are sometimes joined with scarf joints.

55. The roadway railing may be of wood, or a woven wire fencing rail may be used. Wooden railings may be fixed in various ways. One way is to tenon the rail posts into the transoms, which project 2 ft. beyond the roadway on each side to take the railing post struts. In this case the road planks come entirely inside the railings. A better and stronger way is to bolt the posts to the side of the road girders or the transoms, taking them down through the road planks, and to prolong the road planks where necessary to take the railing post struts.

56. (6) *General.*—The size of the main cables depends on the span and the weight of the bridge. For fairly large spans of 150 to 200 ft. 4 to 5 inch circumference steel wire cables are generally sufficient. For the standards of the piers 15 × 10 inch sawn posts are suitable for similar spans.

Strong cross winds are dangerous to suspension bridges owing to the swaying caused. To check this wire ropes may be fastened to the stringers and anchored to the bank both up and down stream.

H. *Culverts.*

57. A culvert is a covered drainage channel used to conduct water under a road, railway or embankment, the name being generally confined to those of a span not exceeding 12 ft., the minimum span (or diameter in the case of a circular pipe), usually being 2 ft.

58. (1) *Timber culverts.*—Culverts are made of many types and different materials. In the forests they are most frequently made of timber. The simplest form of all is a hollow tree trunk, and these, when available, can often be used to carry the drainage of a small depression under a road. Timber culverts of spans from 4 to 12 ft. can be made of the same type as simple girder bridges already described. Smaller ones of 3 to 4 ft. span can be made entirely of poles as follows:—There should be at least one ft. of earth over the top of the culvert, the actual depth of earth varying with the distance from road level to the bed of the waterway. In this example the depth of earth is taken to be one ft. Two posts of from 5 to 8 inches diameter and about 11 to 12 ft. long are driven 3 ft. into the ground at each end of the culvert and from 3 to 4 ft. apart. They should project about 2 ft. above the level of the finished road to form guard posts. Horizontal struts are placed between each pair of posts both at ground level and at the top of the culvert, *i.e.*, about $1\frac{1}{2}$ ft. below road level, and they are slightly notched into the posts and spiked. Between the 2 pairs of main posts shorter intermediate posts 7 or 8 ft. long are driven 3 ft. into the ground along each side of the culvert at about 6 ft. intervals and opposite to each other, so that their tops are about $1\frac{1}{2}$ ft. below road level. Revetment poles are then placed behind them, and horizontal struts placed between the tops of each pair of posts in the same way and on the same level as those between the main end posts. The top of the culvert is covered with poles laid in the direction of the road, and over this a light layer of brushwood and one ft. of earth. Culverts of similar type may be made of sawn timber or offcuts, and rejected sleepers if available, may be made use of.

59. (2) *Dry Stone Culverts.*—These may be made for spans up to 4 ft. where suitable stone is available. If large flat stones are obtainable, they can be covered with single large slabs; otherwise the sides can be corbelled out 6 to 9 inches each layer so that smaller slabs can be used for the final covering. In doing this the ends of the top covering stone should project beyond the inner edges of the stones used in the first layer to be corbelled out. There must be at least 12 inches of earth or other covering over the top slab. The foundations of the side walls must be firm. If there is danger of scour undermining the side walls, it is generally cheaper to pave the floor with an inverted arch than to take the foundations of the side walls below scour.

60. There are various other ways of building small culverts of somewhat similar design ; *e.g.*, reinforced concrete slabs can be used for covering, or stronger, but more expensive, kinds of culverts can be made of brick or stone masonry in lime mortar with arched coverings. For arched coverings the foundations of the side walls must be specially firm. Arched culverts can, of course, be made up to the maximum span of 12 ft.

61. (3) *Tube Culverts.*—Tube culverts of circular section of 2 to 3 ft. diameter are also often made—either of corrugated iron, reinforced concrete, or glazed earthenware, short sections of 1 to 3 ft. length being joined together to form a tube of the necessary length. Ordinary corrugated iron sheets (not thinner than 18 gauge) can be bent into circular cylinders, the 2 edges overlapping and bolted together; but it is better to buy ready made tubes, *e.g.*, Armco, generally in about 3 ft. lengths. To make the culvert a trench with half round base must be prepared, the bottom and sides being well-rammed with earth or stones. Ordinary corrugated iron tubes should if possible be surrounded with lime concrete. Armco tubes do not need a concrete surrounding. Concrete or earthenware tubes must be carefully laid on a well-rammed even bed, and the joints well filled and caulked with cement. Tube

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culverts can be made in a series of 2 or more close together if necessary, but other culverts should always be of one span only, it being cheaper to make them of one larger span than of several smaller spans. Tube culverts must have their ends surrounded with masonry or timber to prevent water forming false channels outside the tube. If there is a considerable height of embankment above the culvert this revetment must be continued up to road level. It may consist of dry stone masonry, stone or brick masonry in lime mortar, or timber.

62. (4) *General.*—Culverts should always be given a good slope longitudinally, especially in the hills, though not so steep as to cause erosion. In level country the height of the culvert must be such that the top of the opening at the upstream end is above flood level of the water at the down stream end. This will minimise the danger of the culvert silting up.

In the hills a well or catchpit must be made at the entrance of the culvert, its bottom being about 1 ft. below the floor of the culvert, so that it may catch silt and rubbish before they enter the culvert. It should be cleared out frequently. This well may be lined with wood or stone, or at greater expense with masonry in lime mortar and cement pointed.

Culvert openings should in general be low and wide rather than high and narrow. This shape reduces the danger of scour, the wingwalls need not be so long, and it may prevent undesirable humps in the road.

J. *Temporary Bridges.*

63. In the forests it may often be unnecessary or inadvisable to build permanent bridges across streams and watercourses. Traffic may be entirely or almost entirely confined to the dry season either on permanent routes or on temporary extraction roads only required for one or a few working seasons. As most watercourses are dry or nearly dry for a large part of the year, it would be a waste of money in the above cases to build permanent bridges capable of withstanding floods in the rains and of lasting for many years. This should always be carefully considered before building a bridge.

64. In cases where a watercourse is dry or practically dry except during the rains, it may be sufficient to cut down the banks into properly graded approaches and improve the stream bed where necessary by removing large boulders in stony watercourses, or

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laying down grass, reeds, brushwood, or poles in sandy or other soft places to prevent carts sinking in. On more permanent roads Irish bridges (paved causeways) and scuppers may often be constructed. These are all really methods of improving roadways and have been dealt with under roads.

65. In streams which contain water throughout the year rough temporary bridges may have to be made to last during the dry weather, being removed before the rains. These may be constructed on the same principles as simple girder bridges, though naturally they need not be so high or so strongly made, as only the dry weather stream has to be allowed for, and they are only erected for one season. Where the span is too great for single girders, short piles can be used, but construction is simplified if, as often, they can be dispensed with. There are often naturally raised portions of the stream bed, and if these occur at suitable intervals and have a sufficiently firm foundation, piers can be made of large logs about 16 ft. long laid across short poles to form a transom on which the road bearers can rest. The roadbearers for each span consist of 3 logs about 16 inches diameter and of any necessary length up to about 30 ft. laid from the banks to the transom or from transom to transom, their ends overlapping. Decking may be of 6 × 3 inch planking spiked to the middle girders and held down at each side by 12 inch diameter logs. For decking instead of planks poles or brushwood can be used covered with grass or reeds and about 6 inches of earth. This is cheaper, but needs frequent repairs.

66. For similar bridges piers can be made of dry rubble or cribwork, or trestle bridges can be made, as already described. For heavy cart traffic for a whole working season trestle bridges are not so suitable as the above described type, as it is difficult to make them strong enough to last a whole season, their construction is more complicated, and if wire or rope lashings are used they are expensive and liable to be stolen.

6. River Training and Protection of River Banks.

67. A. *General.*—It may sometimes be necessary to take steps to prevent the erosion of river banks to protect the abutments of a bridge, or a road or building in danger of being washed away. The usual method is indirect by diverting the current away from the bank to be protected and into the desired channel by means of spurs projecting into the stream. Direct strengthening of the banks by

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retaining walls or by some other form of revetment is more expensive, and is not often done unless spurs are impossible.

68. B. *Spurs.*—These are artificial banks projecting out into the bed of the stream either at right angles to or at an angle with the current. They check the force of the water, and divert the main current from the banks, and cause silt to be deposited both above and below. They should commence some distance above the point to be protected. Perpendicular spurs are useful against weak currents, and if built strongly of stone are generally preferable even against swift currents. Timber and brushwood spurs are weaker, and should generally be built obliquely down stream making an angle of not more than 30° with the current. If the spurs are oblique, the force of the current is not wholly checked, and it runs down the side of the spur, and is more likely to undermine and destroy the toe, *i.e.*, the upstream corner of the outer end. If they are perpendicular the velocity of the stream is effectually checked, and there is much less danger of the toe being undermined, though the spur must be much stronger to meet the full force of the current without being entirely carried away.

69. Spurs should not project too far into the bed of the stream, and the total width of waterway must not be greatly reduced, or the height of the water will rise and cause further trouble, and there will be a danger of the current being diverted against the opposite bank and damaging it. Thus a larger number of short spurs is better than a smaller number of long ones.

70. Each spur will normally protect a length of bank downstream five times and upstream three times its perpendicular distance from the bank. But this does not mean that if the perpendicular distance is say 50 ft. the distance along the bank between spurs should be 400 ft. They should be much closer than this:—*e.g.*, in a silting stream in the plains of average velocity, if the spurs are 100 ft. long and at an angle of 30° with the current (making the perpendicular distance 50 ft.), they may be 150 ft. apart. The tops of the spurs should if possible be well above H.F.L. Their heads should be built well into the bank, and their foundations are important, especially at the toe, where they should be several feet below the bed of the stream and specially strengthened.

71. The materials used for spurs depend chiefly on what is available, and also on the force of the current. Where the current is

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not very strong, and no stones are easily obtainable, (as in many streams in the plains), two or more rows of posts or piles may be used with bamboos or branches interlaced, the space between being filled with brushwood firmly pressed in and bound down with wire, or with kankar if available, or with sacks filled with sand. Where broken rock or stones of angular shape are available the spur may be built entirely of stone, using the largest pieces possible, especially at the base and the exposed side. The toe should be specially strengthened, and mortar may be used here for extra strength. A projecting apron of stonework on the upstream side of the spur going below the stream bed is useful. The face of the stonework should be sloped back at 1 in 1, the top being only a few feet wide. If large angular stones are not available, wooden cribwork frames can be filled with round boulders, or failing this with kankar or with sacks filled with sand. The construction of these is the same as already described for cribwork piers. They can be made of any convenient size, say 10 × 10 ft. at the base, but not usually more than 8 ft. high. They must be securely fastened to each other. If a spur must be more than 6 or 7 ft. high, it will have to be built in two or more stories, and may be strengthened with piles the full height of the spur driven in between the cribwork frames, and to which they may be fastened. If stones are not available and the spurs must be stronger than is possible without the use of stones, blocks of cement concrete, preferably reinforced, may have to be used.

Spurs can generally be built when the stream bed is dry. If it contains deep water throughout the year, and cribwork frames are being used, they can be made up on the bank, floated out with a few large stones in the bottom, and sunk in the required position by being gradually filled up with stones.

C. *Direct Strengthening of Banks.*

72. This, if necessary, may be done on much the same principles as above, according to the material available and the degree of protection required; *e.g.*, timber posts and brushwood or planks as revetment, stone retaining walls, etc.

D. *Weirs.*

73. Another form of river training which may occasionally be necessary is the construction of a series of low dams or weirs across a stream bed to reduce the speed of the current and consequent

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erosion by floods. This is most likely to be necessary in hill streams, and may be combined with afforestation of banks and catchment areas. The effect of a series of weirs is to convert a rapid stream into a number of more level slower moving sections alternating with vertical falls; and by afforestation the rain water is held up and runs off much more slowly into the streams. Thus erosion is stopped or greatly lessened, and the danger of floods and the accumulation of boulders and silt in the plains is considerably reduced.

The construction of weirs is on much the same principles as that of spurs.

Weirs may also be useful below a bridge to check the speed of the current through it, and thus lessen the danger of scour.

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IX. WATER SUPPLY.

1. General.

1. A good water supply for drinking is extremely important. Many diseases are caused by water being contaminated, the bacteria which cause, *e.g.*, cholera, dysentery, and typhoid being conveyed to the human body in drinking water. These bacteria are by far the most important things in water which cause disease. As forest officers are generally responsible for their own water supply, it is essential to be very careful in choosing a suitable source of supply when siting new buildings, and in keeping all existing supplies free from contamination. Water polluted by bacteria cannot be distinguished from pure water by taste, appearance, or smell. It is, therefore, necessary to know in the first place in what ways water is likely to become polluted, and thus avoid choosing as a source of supply any that is likely to be polluted, and also prevent any existing supply from becoming so polluted. This is the most important. But in cases where doubtful water has to be used, we must know how to purify it.

2. *Contamination.*

2. Human excreta from persons suffering from disease contain large numbers of the bacteria which convey that disease. By far the commonest way in which water picks up these dangerous bacteria is by coming in contact with contaminated excreta as it flows over the ground or through the surface layers of soil.

Thus water from most ordinary surface wells near villages, and stagnant water from ponds and tanks near villages, and water from streams and rivers anywhere near human habitations should always be suspected, and never used without purification.

3. *Purification.*

3. The easiest method is by boiling. If water is kept actually boiling for one minute or longer, dangerous bacteria will be destroyed. It is safer to boil it for at least 5 minutes. It should be used fairly soon after boiling, and not kept for long in an open vessel. It can fairly quickly be cooled by putting it in an ordinary porous earthenware pot.

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Filtering water is a good method, but special patent filters have to be used, and will probably not be very easy or satisfactory in the jungle.

Another method is sterilization by chemicals. The commonest is by using permanganate of potash. This is useful for general purification of wells and storage tanks, but it is always safer to boil the water as well before drinking. Half a grain per gallon of water is enough, and sufficient for the whole well should be mixed in a bucket and lowered into the well. If exact measurement is difficult, sufficient should be used to colour all the water a pale pink. Chlorogen, a special preparation containing chlorine, is probably the best sterilizer, and if properly used water can be made quite safe by this means, though it is apt to have a slightly unpleasant taste. It is bought in special bottles with directions for use on the bottle.

For cleaning muddy water powdered alum is useful. From 1 to 6 grains of alum per gallon of water, or a maximum of 1 teaspoonful to 10 gallons, is necessary according to the degree of muddiness. Add the alum some hours before the water is required.

N.B.—1 c. ft. water equals 6¼ gallons, and 1 gallon water weighs 10 lbs.

4. SOURCES OF SUPPLY.

A. *General.*

4. The original source of all supplies of fresh water is rain. When rain falls, part of the water runs more or less directly into streams and rivers, part is directly evaporated into the air, or is absorbed by vegetation, and part sinks into the ground either directly where it falls, or by gradually sinking in from streams and rivers or pools and lakes. When water sinks into the ground much is temporarily absorbed by the soil or rock it passes through, and is subsequently dried up either by evaporation or absorbtion by vegetation. But considerable quantities of surplus water normally continue to descend until stopped by strata impermeable to water. In level country this surplus water generally collects and remains stationary at a varying depth below surface depending on the depth of the impermeable strata and the amount of surplus water. In forest areas in the plains of the United Provinces this subsoil water level varies normally from a few feet below the surface in low-lying areas (it may of course be at the surface in water logged places, or above it where ponds are formed) to as much as 70 ft. in the higher plateaux. In hilly country the impermeable strata are not generally level. Thus when subsoil water is stopped by such a stratum it will flow slowly down over it until held up by a rise in the stratum, or until the stratum emerges at the surface of a hill slope, when the water comes out in the form of a spring. Thus in hilly country the subsoil water level is very uncertain, and may be only a few feet down in depressions and valleys, or may be hundreds of feet down; *e.g.*, in the United Provinces Bhabar at the foot of the Himalaya and in many places in the hills proper.

B. *Classification of sources of supply.*

5. The sources of water supply may, therefore, be any of the following:—

(1) Streams and rivers.

(2) Lakes and ponds in which stream or river water is held up by natural or artificial barriers, or tanks filled directly by rain water.

(3) Natural springs.

(4) Wells which are sunk artificially to tap the subsoil water.

These will be discussed in greater detail.

6. (1) *Streams and rivers.*—Streams draining rocky and uncultivated ground are generally pure, but where villages are near the water is nearly always contaminated. For this reason water from large rivers is generally unsafe, and if such water has to be used it should be collected from the middle by boat. Running water will, however, after contamination purify itself after travelling a considerable distance in a river, though this should never be relied on. If river or stream water has to be used, various precautions should be taken. If possible it should be purified by boiling or other means, and if villages are near, always draw it upstream from them. In small streams if there is only a small flow of water, as *e.g.*, in the dry weather, a shallow well 2 to 3 ft. deep may be dug in or near the bed of the stream and a few feet from the main flow of water. Water percolating through into this well will be naturally filtered and will be safer. The well may if necessary be lined with a revetment of split bamboos or branches, etc. Stream and river water is especially

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dangerous at the beginning of the rains and during floods, as contaminated surface deposits will have been collected and brought down in the water.

7. (2) *Lakes and Ponds.*—Stagnant water in small ponds is always dangerous. Large lakes in hilly country may be quite safe, but if there are villages near the banks, the water should be collected from the centre.

8. (3) Springs.—These are generally quite safe, but it should be seen for certain that there is no chance of pollution; *e.g.*, a spring may not be from a really deep source, but may come from a polluted stream which went underground temporarily a short way up the hillside. A spring may also contain salts or sulphur compounds dissolved from the rocks the water has passed through and be unfit for drinking.

If the water supply for a proposed dwelling house is to be from a spring, it should be seen that the supply is sufficient, and it should be tested at the driest time of year.

Water supply in the hills is generally from springs, either close at hand, or brought from a distance in pipes or water channels. The latter should if possible be covered, and brought by a route as safe as possible from pollution.

9. (4) *Wells.*—These are the usual form of water supply in the plains. There are 3 types:—

(a) *Shallow wells* sunk through fairly soft ground down to subsoil water level, the usual maximum depth being about 70 ft. If made with a waterproof lining and protected at the surface from drainage, the water will usually be fairly pure, as it will have filtered through a considerable depth of soil.

(b) *Short tube wells* in soft soil, used with an ordinary valve pump with a maximum safe depth of about 20 ft. They are useful in sandy and other soft soils if the water is not more than 20 ft. below the surface. They are especially useful as temporary wells, as they are easily sunk and easily removed for use elsewhere.

(c) *Deep tube wells* carried down by boring to considerable depths through impermeable strata into water bearing layers below. Special boring apparatus and pumping machinery is necessary, and they are not generally practicable in the forest.

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5. CONSTRUCTION OF WELLS.

A. *Ordinary Shallow Wells.*

10. (1) *Selection of Site.*—When buildings have to be erected in a new site to be supplied by well water, care should be taken before building is started that there is a sufficient supply of good water for a well at a convenient distance. It may help to examine any existing wells in the neighbourhood, and to try and find out from any exposed outcrops if the stratification around the existing wells and the proposed site is similar or not. The comparative level and general formation of the ground should also be compared. If there is any doubt, a test well should if possible be sunk by boring or other means. To decide as to the most likely place to find water near the surface, the followng indications may help:—Water is more likely to be found where grass remains green during the hot weather; where denser mists arise in early morning and evening; where insects hover in a column, remaining in one place at a fixed height above ground; in valleys just above a contraction in width, or at the point of junction with a branch valley; where a line of rocks shows just above ground—on the uphill side of the rocks a short way above them.

A well should never be sunk near latrines, cattle sheds, burial grounds, stagnant pools, or other sources of contamination, nor too near a road, dust from which may pollute it. It should be sited at a low level to reduce the depth of excavation, but not in the lowest ground, or it will be difficult to arrange for surface drainage away from the well.

11. (2) *Details of construction.* (a) *General.*—When making an estimate for a well, it is necessary to know the approximate depth it will be. This will probably have been decided when choosing the site, either by comparing the depth of neighbouring wells or by one of the other methods already mentioned. The rate paid for excavation will increase as the digging gets deeper, and it is usual to increase the rate after each 10 ft. of depth. The best time for sinking wells is in the hot weather when the water level is at its lowest.

12. The usual method of constructing a well with masonry lining or steining is to dig a pit of the required shape down to water level or as near it as possible; then to lay a wooden curb at the bottom and build up the steining on this, gradually sinking it to the required depth below water level. It sinks partly by the weight of the steining and partly by further excavation under the curb. The minimum inside diameter of wells is usually 4 ft. The different stages of construction will now be dealt with in greater detail.

13. (b) *Excavation.*—The method will depend on the nature of the soil. If it is stiff enough the digging may be carried down vertically till water level is reached, making the pit 2 ft. larger in diameter than that of the outside of the steining. If the soil is sandy or unstable the pit must be made with sloping sides, or must be lined with timber or other form of revetment. The latter is expensive and troublesome, and it is generally considered better to make a wide pit with sloping sides. A windlass may be erected over the pit, so that men can go up and down and soil be brought up by ropes, but frequently a spiral staircase is cut in the earth round the sides of the pit.

Another method, if the soil is very unstable, is to start by laying the curb on or very near the surface and to sink the steining gradually as the soil is excavated from beneath. This is of course more difficult and laborious.

The shape of the pit depends on the kind of steining. Masonry is generally circular, and timber often square. Permanent forest wells are usually of masonry steining for the whole depth of the well. This type will therefore be considered first in detail.

14. (c) *Well Curb.*—The excavation having proceeded down to or as near as possible to water level, the curb is then laid on an absolutely level foundation. Curbs are generally of timber, but may be of reinforced concrete, steel, or cast iron. A wooden curb consists of 2 or 3 layers, each layer of 2 or more sections, the whole being bolted together with ½ inch bolts and strengthened with fish plates on the upper surface. The species commonly used are *Bombax malabaricum*, *Mangifera indica*, *Eugenia jambolana*, and *Ficus glomerata* or *religiosa*. The curb is in the form of a ring, generally the same size as the steining or slightly larger, and of 6 to 10 inches depth. Its upper surface is flat, and the lower layer is cut away to form a sharp edge on the outside to make sinking easier. On this lower edge an iron cutter in the form of a ring 3 inches deep and ½ inch thick is often fixed.

15. (*d*) *Steining.*—For small wells not more than 10 ft. deep it consists of a 9 inch thick ring of radially shaped bricks or

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stones, or of coursed rubble. For wells of 10 to 40 ft. depth the ring should be 18 inches thick for bricks or radially shaped stones and 2 ft. thick for coursed rubble. For depths of over 40 ft. it should be thicker still. It is possible to use ordinary rectangular bricks as for an arch, but it is advisable to use special radially shaped (wedge-shaped) ones. Mortar of good hydraulic lime or of cement should be used. The inside of the steining is sometimes left without being pointed or plastered. But it is better in order to make sure of excluding surface water to plaster the inside nearly down to water level with ½ inch cement plaster or with thick lime plaster. This is better than pointing. It is also advisable to smear moist clay 6 inches thick on the outside of the steining for 10 ft. down from ground level.

16. Before starting to build up the steining, in order to secure the curb to the masonry and to prevent the lower part of the cylinder getting detached during sinking or through subsequent settlement, 6 1-inch vertical iron tie rods 10 ft. long are passed through the curb at equal intervals, being secured below by the bolt heads. The building of the steining on the curb will then commence round them. When it has reached to the top of the tie rods, a circle of flat iron 3 × ½ inches is laid on top and secured to the tie rods by nuts. The masonry should then be left until the mortar has set before commencing sinking the steining.

17. (e) *Sinking the steining.*—This is normally done by building up the cylinder, when the weight of the masonry makes it sink with the help of excavation under the curb. This excavation has eventually to be done below water level. 'Jhams' or dredgers may be used, but it may be necessary to employ special men who will go down under the water, especially if stones or blocks of kankar have to be pulled out from under the curb. It is advisable if possible to sink the steining 10 ft. below water level. If necessary the cylinder may be weighted on top to assist sinking. During sinking and building up it is very important to keep the cylinder absolutely vertical, and it should constantly be tested by 3 or 4 plumb lines suspended from the top. If it is found to be leaning at all, extra weights should be placed on the highest side, and excavation done on that side only till the cylinder has become vertical again.

18. In many parts of the plains of India the subsoil water is in sand with layers of kankar and clay interspersed at irregular

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depths. The well curb should if possible finally rest on a firm layer of clay, being carried down 2 ft. into it. If the depth of water is then still insufficient, a hole 6 to 9 inches diameter should be bored with a jumping bar or other suitable instrument in the middle of the well through the clay to see if water bearing sand can be reached below. If it is reached, the water will pass up through the hole, and generally a sufficient supply will be maintained. The hole need not generally be lined with a pipe.

19. (f) *Earth Filling, Platform, etc.*—When the sinking is finished, and the steining has been carried up 3 ft. above ground level, the vacant space round the outside should be filled in and thoroughly rammed. It is essential to leave this rammed earth till after the following rains to allow for subsidence before building a platform above ground level round the steining. The top of the steining should have a slight outwards slope to prevent water running off from it into the well. The platform is best made of plastered brickwork or concrete terrace, and should be at least 4 ft. wide and sloping outwards to a masonry or concrete lined drain leading round it and away to a distance of 20 to 30 ft. from the well. The mouth of the well should have a wooden cover with a hinged lid, the planking being tongued and grooved to fit close and keep out dust, etc. It is also advisable to have a wooden frame over the well supporting a wooden pulley or roller for a rope or chain.

20. (g) *Other forms of well lining.* (I) *Timber.*—Timber is sometimes used for temporary wells. The simplest form is one or more hollow tree trunks. A more elaborate method is to use a sawn timber lining of square section the sides being about 4 ft. long. Frames of 4 to 6 inch square timber are placed at vertical intervals of about 4 ft. supported by vertical struts spiked at both ends to the frames, and 2 × 10 inch planking is fixed outside to form the lining. If the soil is firm enough, a straight-sided pit can be dug first, and the lining built up from the bottom; or for short wells it can be made up on the surface and lowered bodily into position. If the soil is not firm enough for this, and cannot stand by itself, the lining is constructed in sections from above downwards by underpinning. A pit is first dug down to the depth at which the sides will stand by themselves, and the lining built up to the top. A small pit is then dug 4 ft. down, and a hardwood block placed at the bottom, and sloping struts placed under the completed part of the lining butting against this central block. Sufficient earth is cut away to enable these struts to pass from the central block to the lining above, which is thus supported, and the pit can then be enlarged to its full size. A new section of lining is then made and the props removed. The whole operation is repeated until the required depth has been reached.

21. Underpinning is also sometimes employed in the case of a brick steining in stiff soil, when for any reason the excavation has not been carried down to water level and the steining fails to sink by ordinary means. In this case a fresh curb has to be added every time the pit is deepened, the under surface of the curbs being flat.

22. (II) *Corrugated Iron.*—For temporary wells corrugated iron sheets may be used instead of planking outside a timber framework such as already described, or they may be used alone as cylinders, as in corrugated iron culverts. In the latter case one sheet may be bent round to form a small cylinder, or each sheet may be bent to a semicircle, and 2 sheets bolted together to form one larger cylindrical section. In either case all adjoining sheets must overlap and be bolted firmly together, and some suitable waterproof substance like hot pitch be used to caulk the joints, being applied on the inside of overlapping surfaces before they are bolted together.

23. (III) *Earthenware Cylinders.*—These are sometimes used in a similar way, being about 3 ft. diameter, and made with special rims so that they fit tightly on to each other.

24. (IV) *Reinforced concrete.*—Is often used for wells now-a-days.

B. *Short Tube Wells.*

25. These consist of an iron tube of about $1\frac{1}{4}$ inch internal diameter in short sections generally 6 ft. long connected by iron sockets $2\frac{1}{2}$ inches long, into which the ends of each section are screwed. The first or bottom section has a strong steel point welded into it, and above the point the tube is perforated with about 300 small holes $\frac{1}{8}$ inch diameter, which let the water in. The tube is driven in one section at a time by blows delivered by a cast-iron monkey about 84 lbs. in weight. To drive the well, make a hole about 2 ft. deep with a crowbar and insert the first section of tube into it. A steel driving cap is then screwed on to the top of the tube, and then a lengthening bar is fitted into the top of the tube. The monkey, which has a hole through the centre, is then dropped over the bar and rests on the driving cap. A tripod with attachments for 2 pulleys supports the lengthening bar, which passes freely through its top. The monkey has 2 ropes attached to it, which pass over the 2 pulleys. It can thus be raised by 2 men and dropped on to the cap, and in this way the tube is driven in, great care being taken to see that it is kept vertical. When the first section has been driven in, the cap is unscrewed and another section of tube screwed on, and driving started again. This is repeated till the necessary depth has been reached. A plumb line dropped down the tube will show when water is reached.

26. Another arrangement is to have the pulleys fixed to the top of the lengthening bar, and to have no tripod, but to keep the whole thing steady and vertical with 4 guy-ropes fastened to the top of the bar above the pulleys and held by 4 men. In this case the pulleys and ropes descend with the lengthening bar and tube as the latter is driven in.

When the complete tube has been driven in, the valve pump is screwed on to the top. If, as often happens, the bottom of the tube becomes choked, special cleaning tubes are necessary. Wells of this type cannot be used in rocky ground or heavy clay soils.

A similar type of well can be driven to much greater depths than 20 ft. in suitable ground, but force pumps are required.

The tubes may also be of larger diameter, *e.g.*, 2 or 3 inches.

6. PROTECTION AND CLEANING OF ORDINARY WELLS.

A. *Protection.*

27. Finishing off the top of the well with a 3 ft. high parapet, sloping platform, drain, and wooden cover, as already detailed, are essential means of protection from contamination by surface water, though often omitted for economy.

No cattle sheds or other temporary huts should be allowed near the well, and a fence should be erected round it to keep out cattle. Elephants should never be allowed inside the fence. A trough for animals to drink from placed just outside the fence is useful. A bucket chained permanently to the well may prevent contamination from vessels brought from houses where infectious diseases are prevalent, and everyone should be encouraged to use this rather than dip their own vessels in the well.

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B. *Cleaning.*

28. Wells should always be cleaned thoroughly at least once a year. The best time is at the end of the hot weather when the water is low, though frequently it is done after the rains and just before the camping season starts. In any case if a well has not been used for some time, it should always have the stagnant water removed before being used again.

To clean a well it should be emptied of all water, and all mud and sediment and refuse removed until the original bottom is reached. To make sure that this is done the original depth up to the top of the parapet or other definite point should be indelibly marked near the top of the steining at the time the well is constructed. The inside of the steining should be scraped and examined thoroughly, and any cracks repaired with cement. In deep wells a layer of poisoned air may accumulate near the bottom when the well is not in use, and before a man goes down to commence cleaning a lighted candle should be lowered to test this. If there is bad air it will extinguish the candle. Bad air can be removed by repeatedly lowering and raising a large bundle of leafy branches or straw. After cleaning, about 100 lbs. of charcoal should be thrown into the well to absorb any remaining impurities. It is also a good thing to use permanganate of potash as already mentioned. A useful way of sterilising the inside of the well lining is to use milk of lime. Some quicklime should be slaked in 3 times its weight of water, and the inside of the steining should be scrubbed down with this, and all dangerous bacteria will be killed.

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